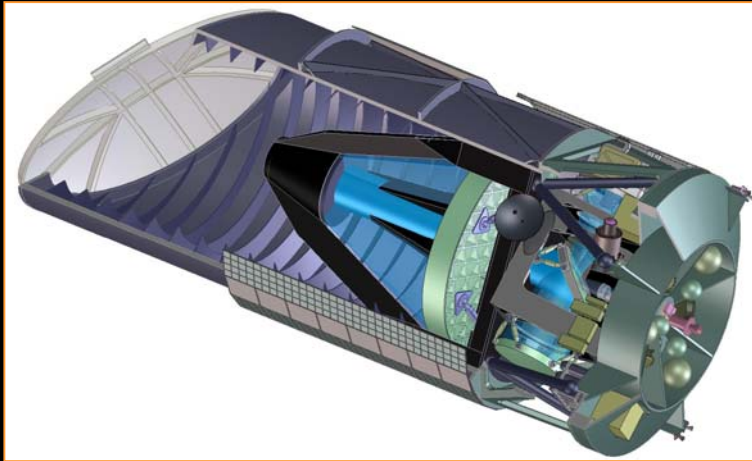
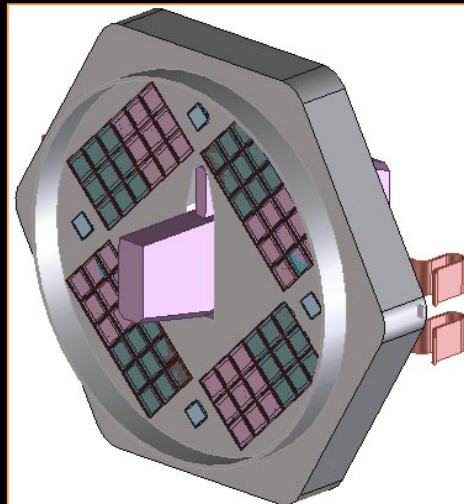


# *SuperNova / Acceleration Probe (SNAP)*



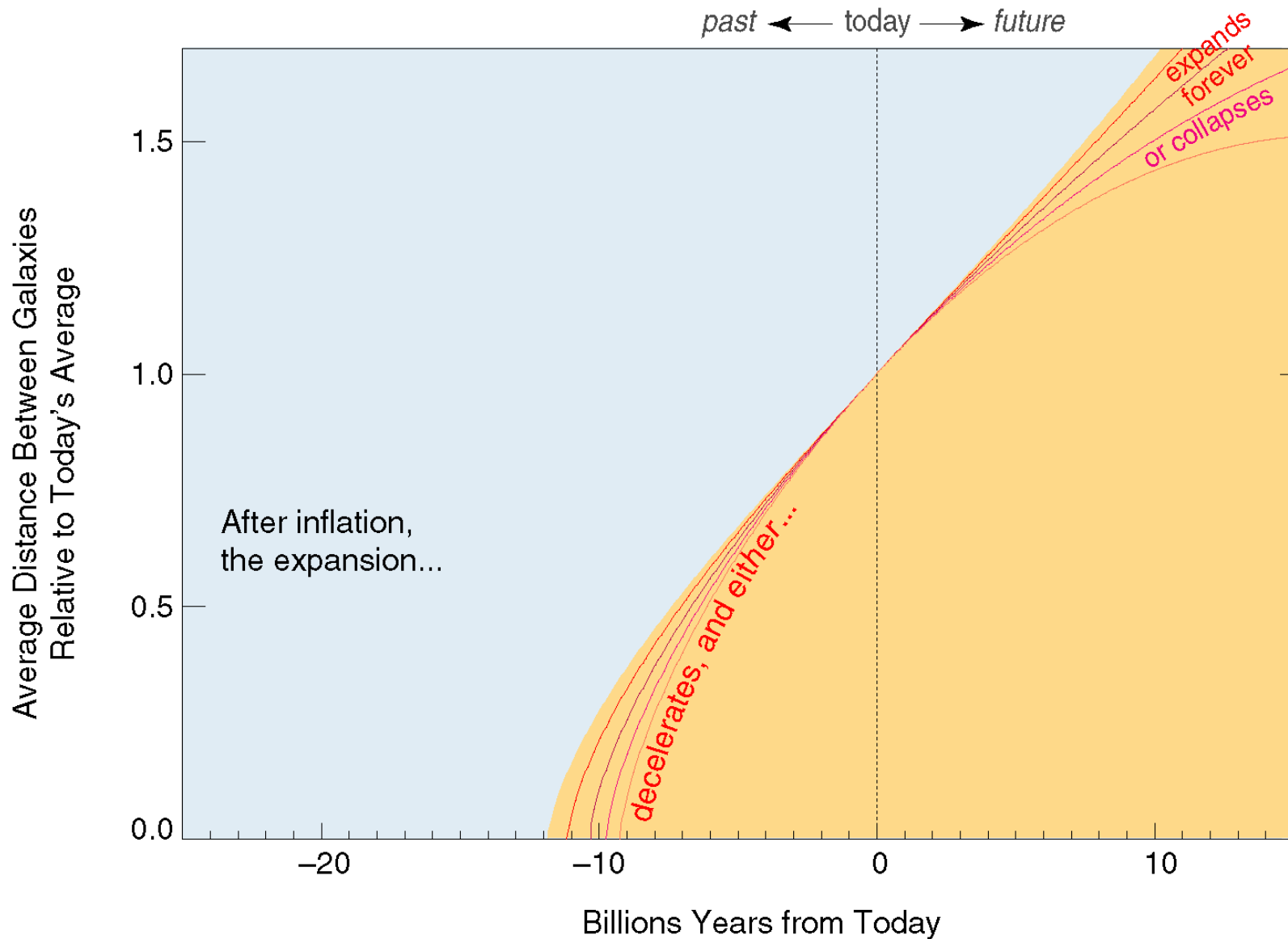
- The Science
- The Technology
- Current Status



*Saul Perlmutter  
HEPAP meeting at LBNL  
March 6, 2003*

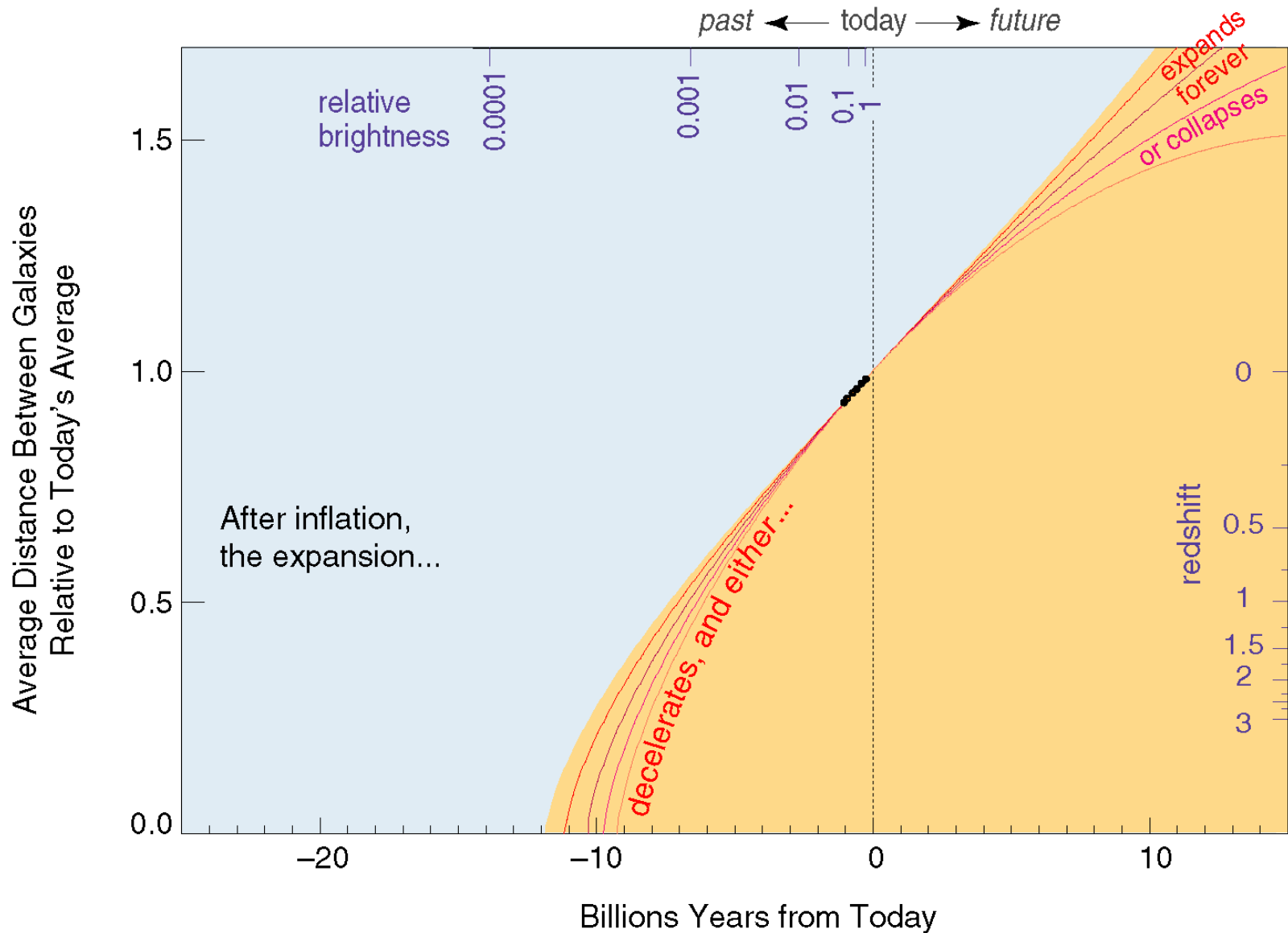


# ***The Expansion History of the Universe***



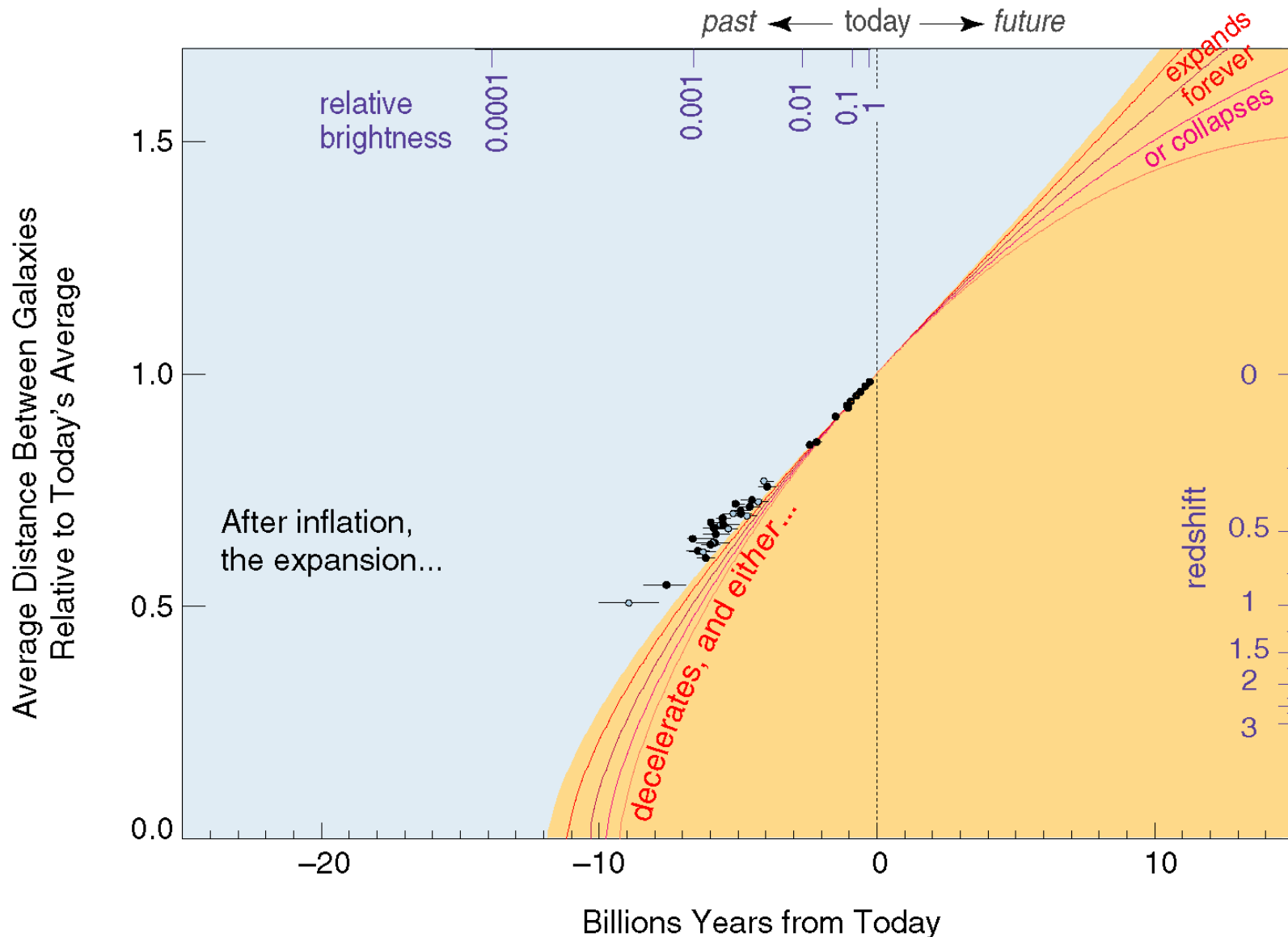


# ***The Expansion History of the Universe***



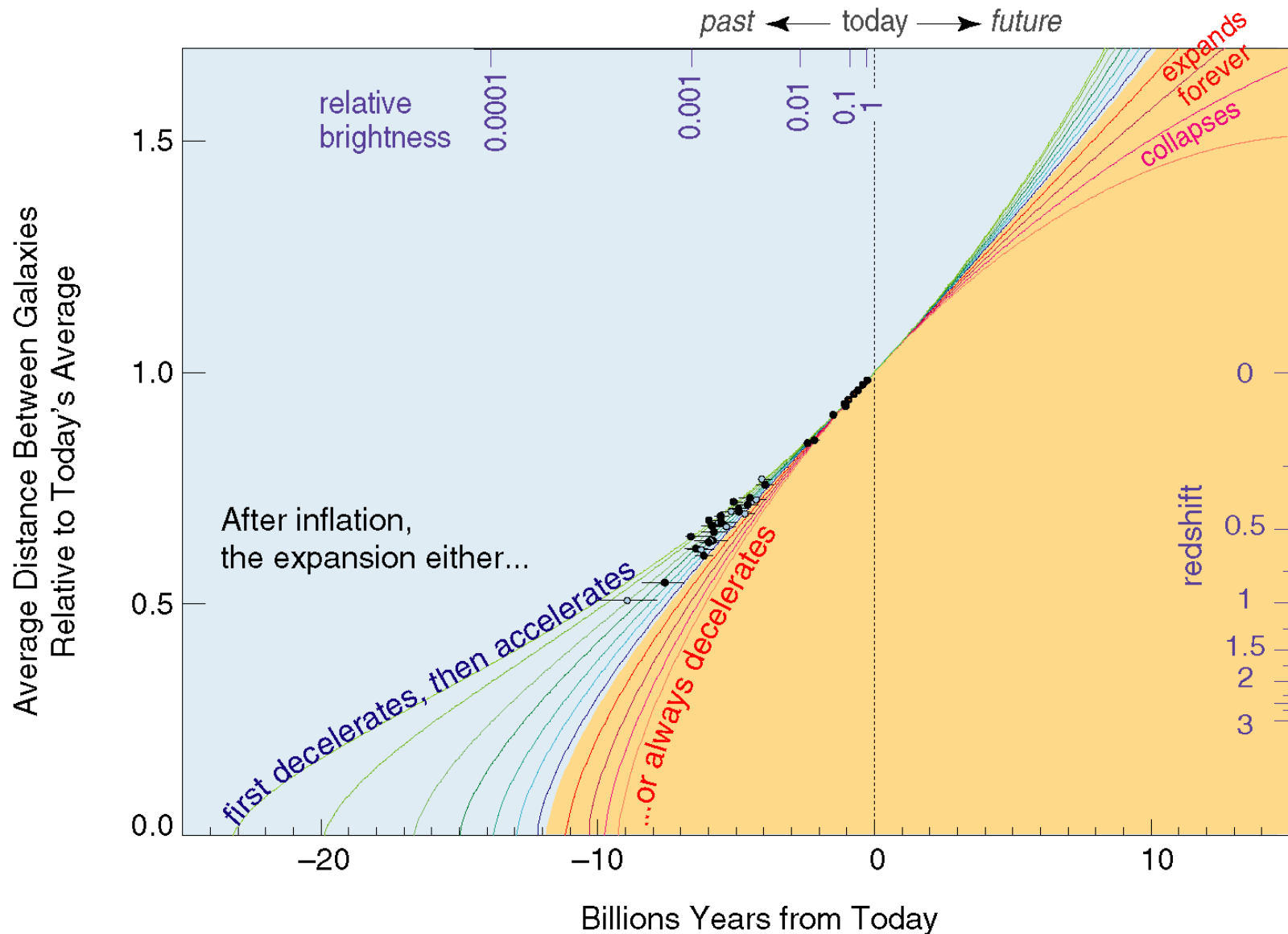


# ***The Expansion History of the Universe***



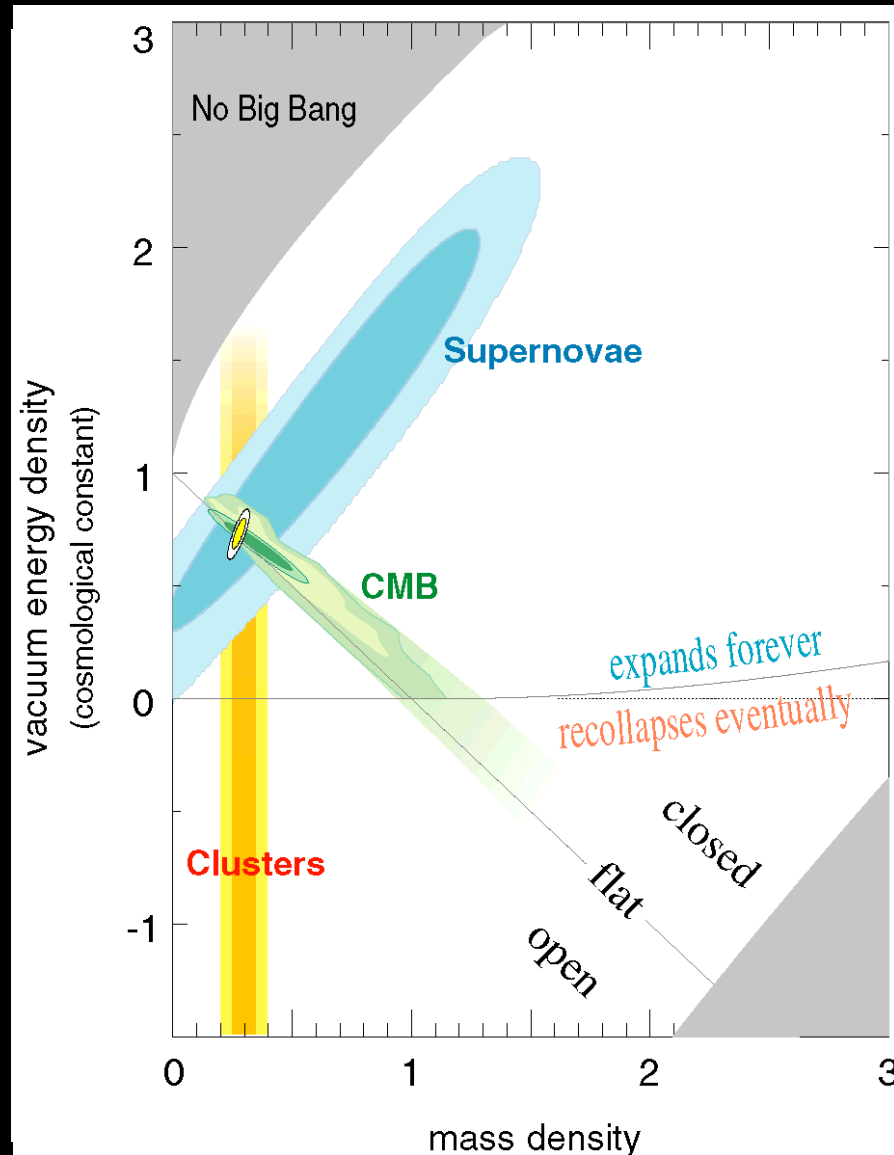


# *The Expansion History of the Universe*





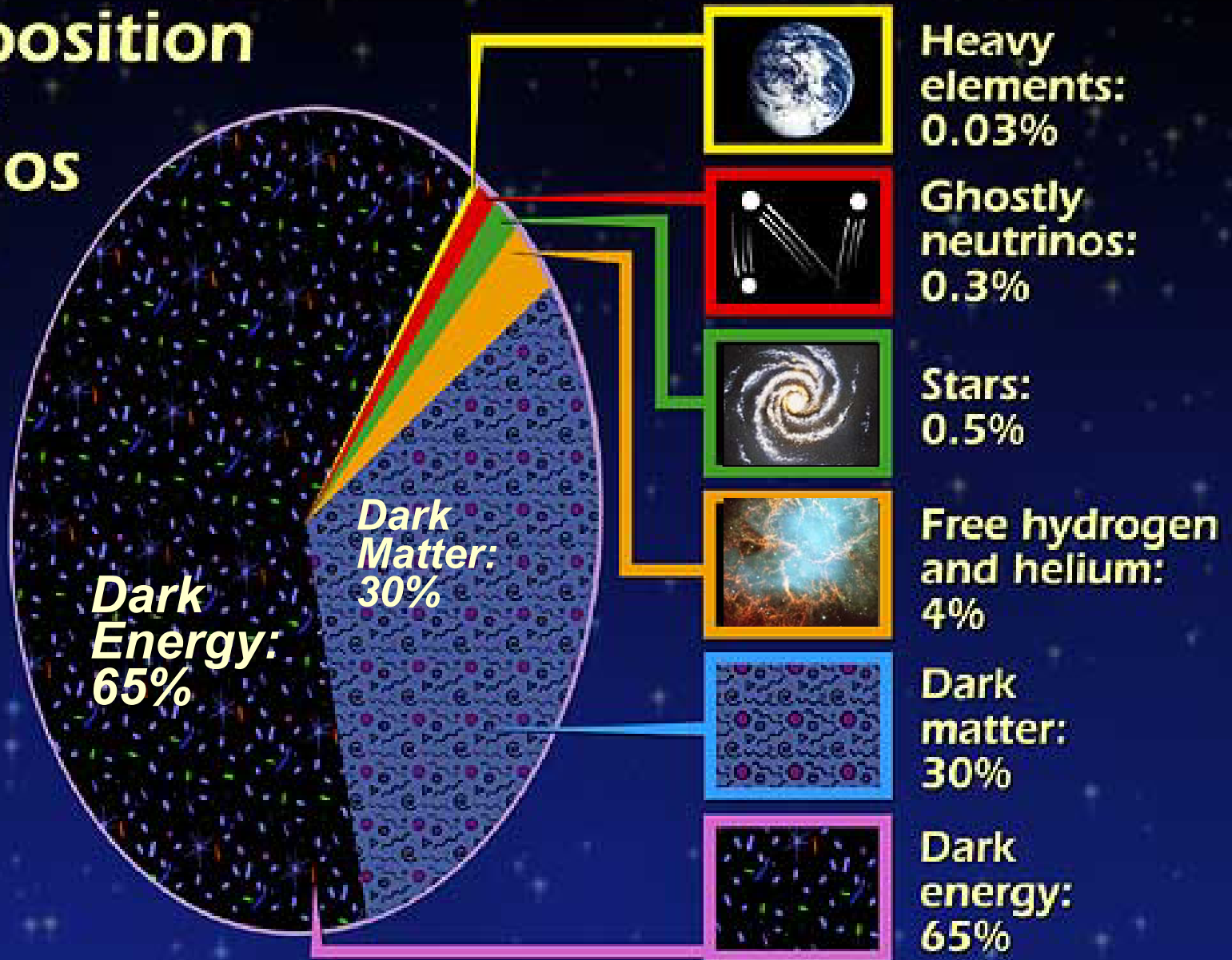
# Current Results on Cosmological Parameters





# *Energy budget of Universe*

## Composition of the Cosmos





# What's wrong with a non-zero $\Lambda$

Two coincidences:

- *Why so small?*

Might expect  $\frac{\Lambda}{8\pi G} \sim m_{\text{Planck}}^4$

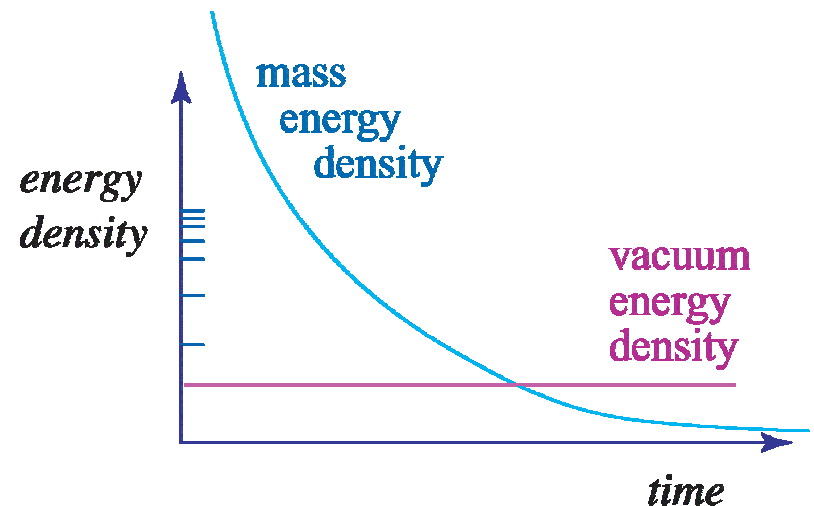
This is off by ~120 orders of magnitude!

- *"Why now?"*

$$\frac{\ddot{R}}{R} = -\frac{4\pi G}{3} (\rho + 3p)$$

*MATTER:*  $p = 0 \rightarrow \rho \propto R^{-3}$

*VACUUM ENERGY:*  $p = -\rho \rightarrow \rho \propto \text{constant}$





# What's wrong with a non-zero $\Lambda$



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**MATTER:**  $p = 0 \rightarrow \rho \propto R^{-3}$

**VACUUM ENERGY:**  $p = -\rho \rightarrow \rho \propto \text{constant}$

*What are the alternatives?*

**New Physics:** "Dark energy":  
Dynamical scalar fields, "quintessence",...

**General  
Equation of State:**

$$p = w\rho \rightarrow \rho \propto R^{-3(1+w)}$$

and  $w$  can vary with time



# *Fundamental Physics Questions*



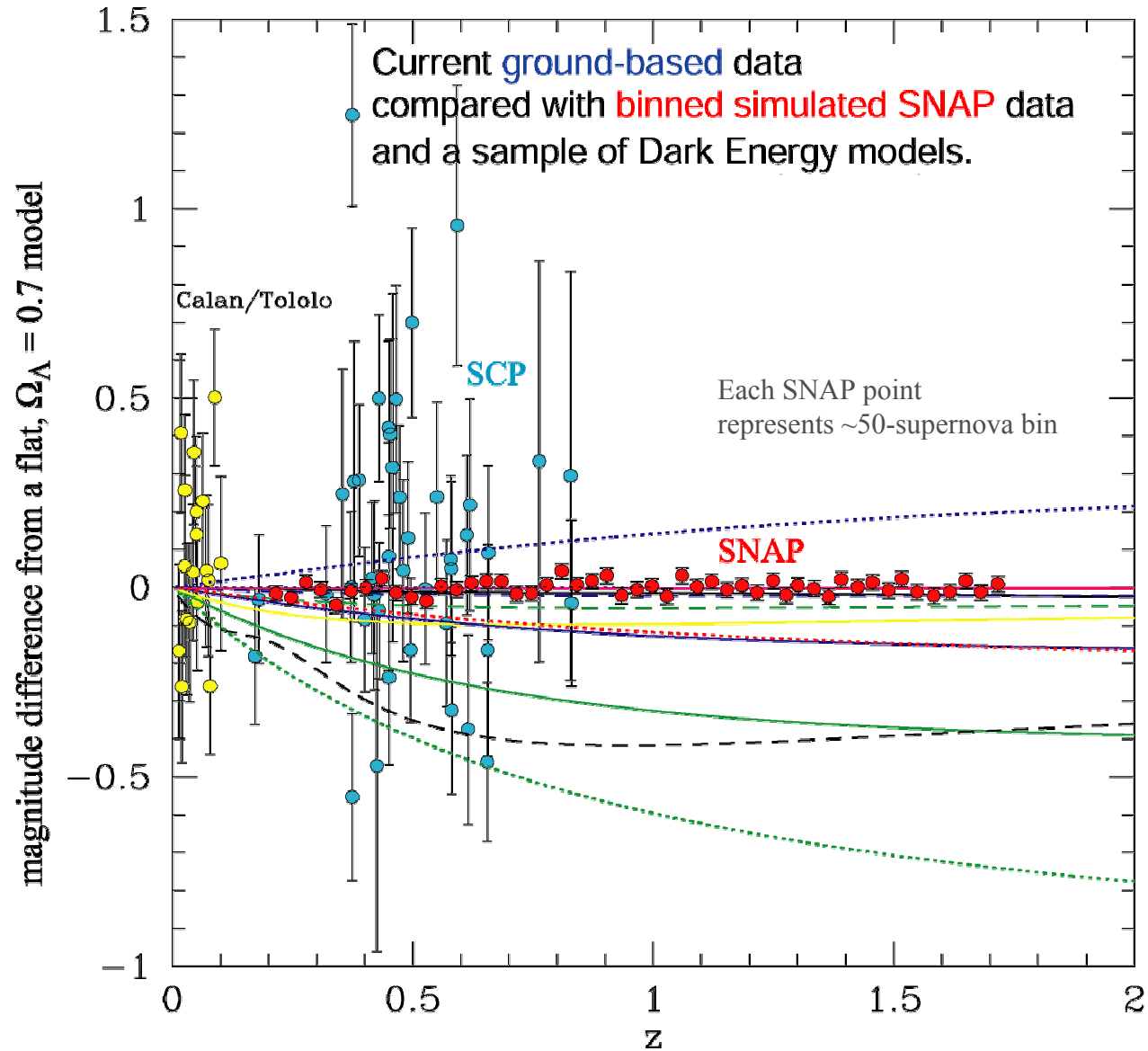
- What is the Nature of the dark energy?
  - The dominant component of our universe.
  - Dark energy does not fit in current physics theory.
  - Theory proposes a number of alternative new physics explanations, each with different properties we can measure.
- Two key contrasting theories of dark energy:
  - vacuum energy, constant over time:

Deep philosophical implications, why are the matter ( $\Omega_M$ ) and energy densities ( $\Omega_\Lambda$ ) nearly the same today, they have totally different time evolution. Why now? Why is  $\Lambda$  so small?
  - or, time dependent possibly a dynamical scalar field:

Might explain  $\Omega_M \cong \Omega_\Lambda$  and so small, we've seen these fields elsewhere in particle physics and in the theory of inflation. Points to new physics.



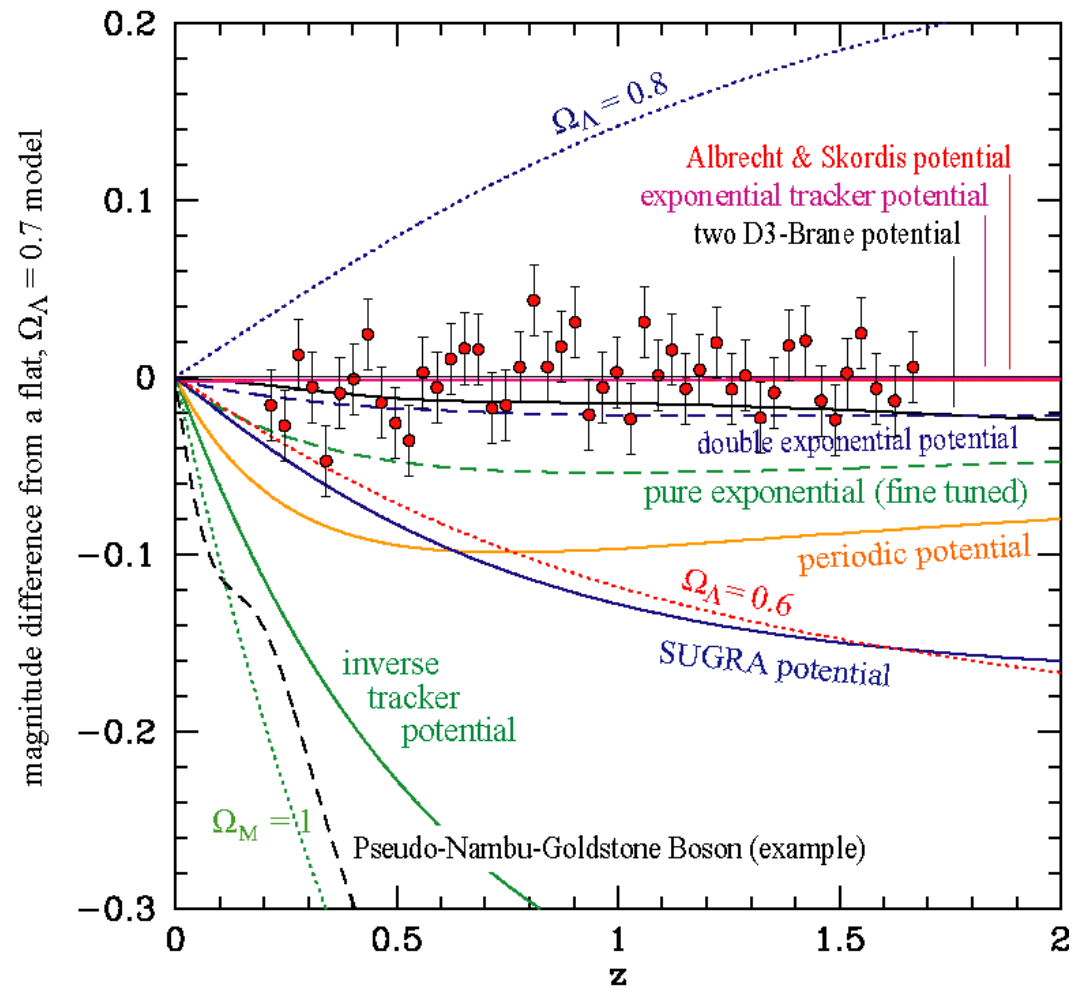
# *Simulated SNAP data*



based on  
Weller & Albrecht (2001)



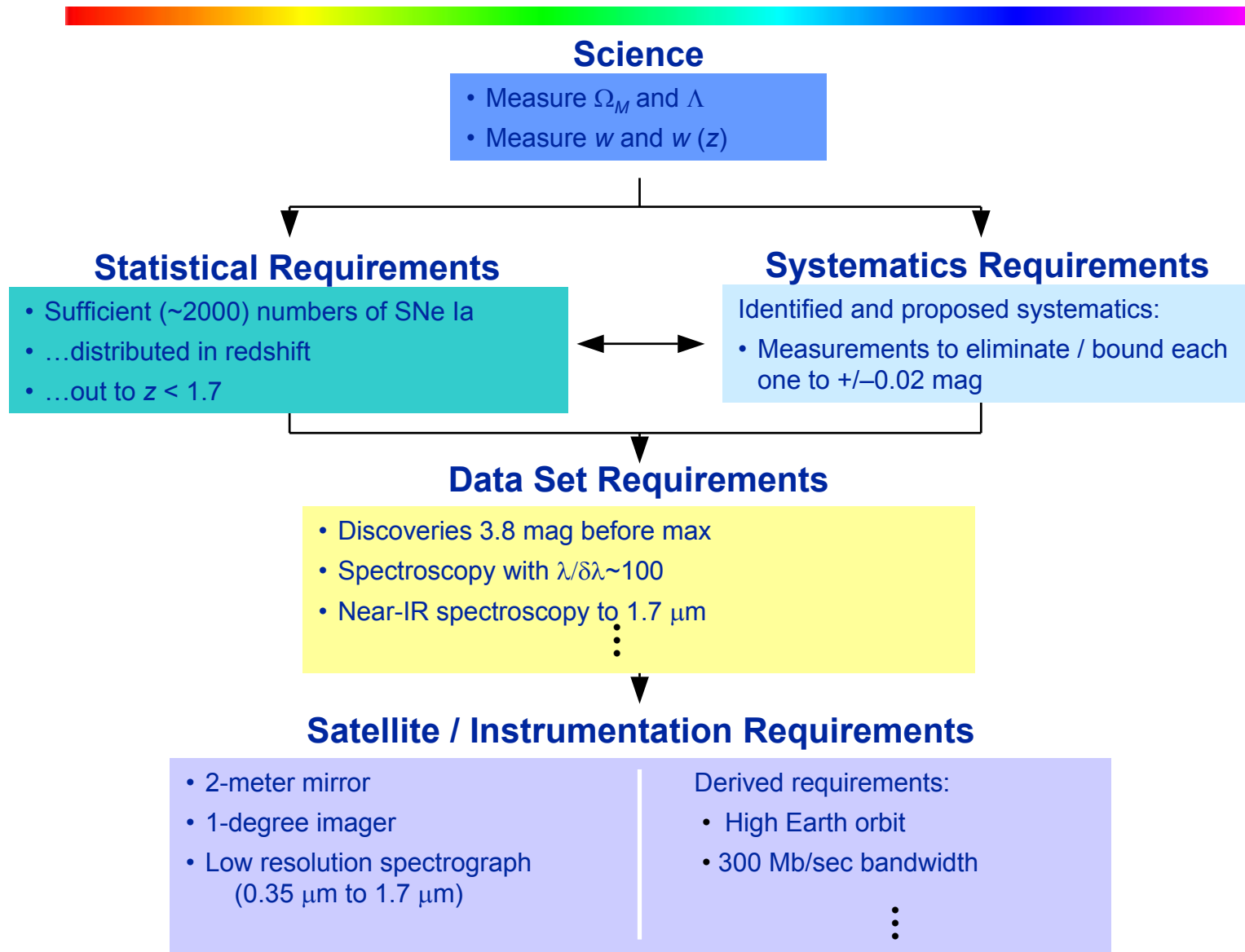
# Understanding Dark Energy



based on  
Weller & Albrecht (2001)



# *From Science Goals to Project Design*





# SNAP Collaboration



**LBNL:** G. Aldering, C. Bebek, J. Bercovitz, W. Carithers, C. Day, R. DiGennaro, S. Deustua\*, D. Groom, S. Holland, D. Huterer\*, W. Johnston, R. W. Kadel, A. Karcher, A. Kim, W. Kolbe, R. Lafever, J. Lamoureux, M. Levi, E. Linder, S. Loken, R. Miquel, P. Nugent, H. Oluseyi, N. Palaio, S. Perlmutter, K. Robinson, A. Spadafora H. von der Lippe, J-P. Walder, G. Wang

**Samuel Silver  
Space Sciences  
Laboratory**



**UC Berkeley:** M. Bester, E. Commins, G. Goldhaber, S. Harris, P. Harvey, H. Heetderks, M. Lampton, D. Pankow, M. Sholl, G. Smoot

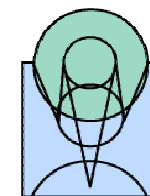


**U. Michigan:** C. Akerlof, D. Levin, T. McKay, S. McKee, M. Schubnell, G. Tarle, A. Tomasch



**Yale:** C. Baltay, W. Emmet, J. Snyder, A. Szymkowiak, D. Rabinowitz, N. Morgan

**CalTech:** R. Ellis, J. Rhodes, R. Smith, K. Taylor



**Indiana:** C. Bower, N. Mostek, J. Musser, S. Mufson

**JHU / STScI:** R. Bohlin, A. Fruchter



**U. Penn:** G. Bernstein

**IN2P3/INSU (France):** P. Astier, E. Barrelet, J-F. Genat, R. Pain, D. Vincent

**IN2P3**

**U. Stockholm:** R. Amanullah, L. Bergström, M. Eriksson, A. Goobar, E. Mörtzell

**LAM\*\* (France):** S. Basa, A. Bonissent, A. Ealet, D. Fouchez, J-F. Genat, R. Malina, A. Mazure, E. Prieto, G. Smajda, A. Tilquin



**FNAL\*\*:** S. Allam, J. Annis, J. Beacom, L. Bellantoni, G. Brooijmans, M. Crisler, F. DeJongh, T. Diehl, S. Dodelson, S. Feher, J. Frieman, L. Hui, S. Jester, S. Kent, H. Lampeitl, P. Limon, H. Lin, J. Marriner, N. Mokhov, J. Peoples, I. Rakhno, R. Ray, V. Scarpine, A. Stebbins, S. Striganov, C. Stoughton, B. Tschirhart, D. Tucker



**\*affiliated institution**

**\*\* pending**



# *SPACECRAFT CONFIGURATION*

Secondary Mirror Hexapod  
and "Lampshade" Light Baffle

Secondary Metering  
Structure

Primary Solar Array

Primary Mirror

Optical Bench

Instrument Metering  
Structure

Tertiary Mirror

Fold-Flat Mirror

Spacecraft

Shutter

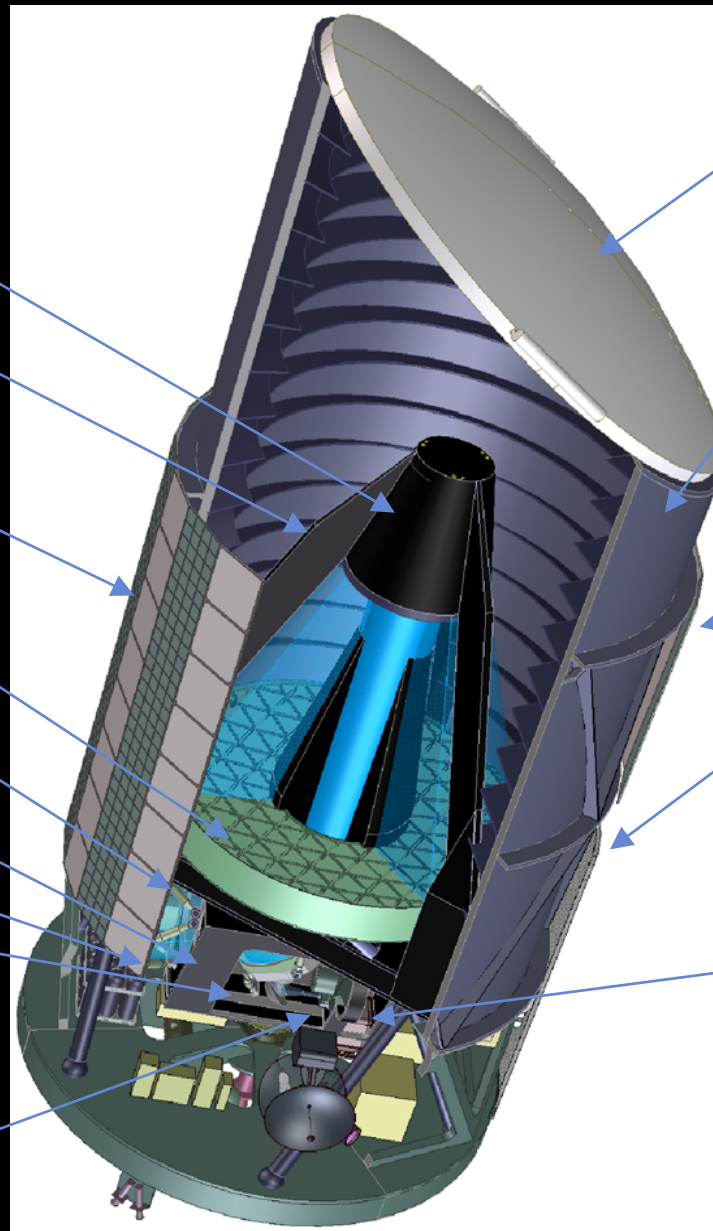
Door Assembly

Main Baffle Assembly

Solar Array, 'Dark-Side'

Instrument Radiator

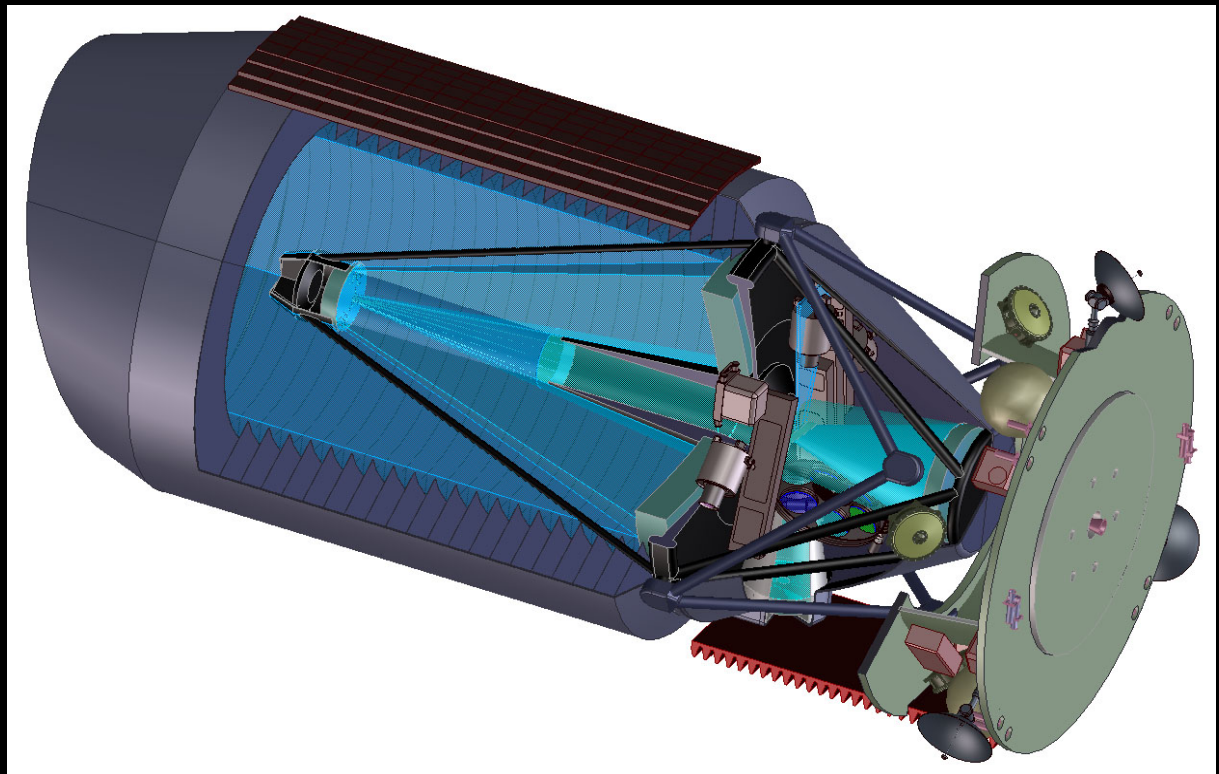
Instrument Bay





# *Space Mission*

- SNAP a dedicated experiment to study dark energy
- Large Field of View: to see lots of SNe, has half-billion pixel mosaic camera ( $\sim 100\times$  larger Field than Hubble)





# *From Science Goals to Project Design*



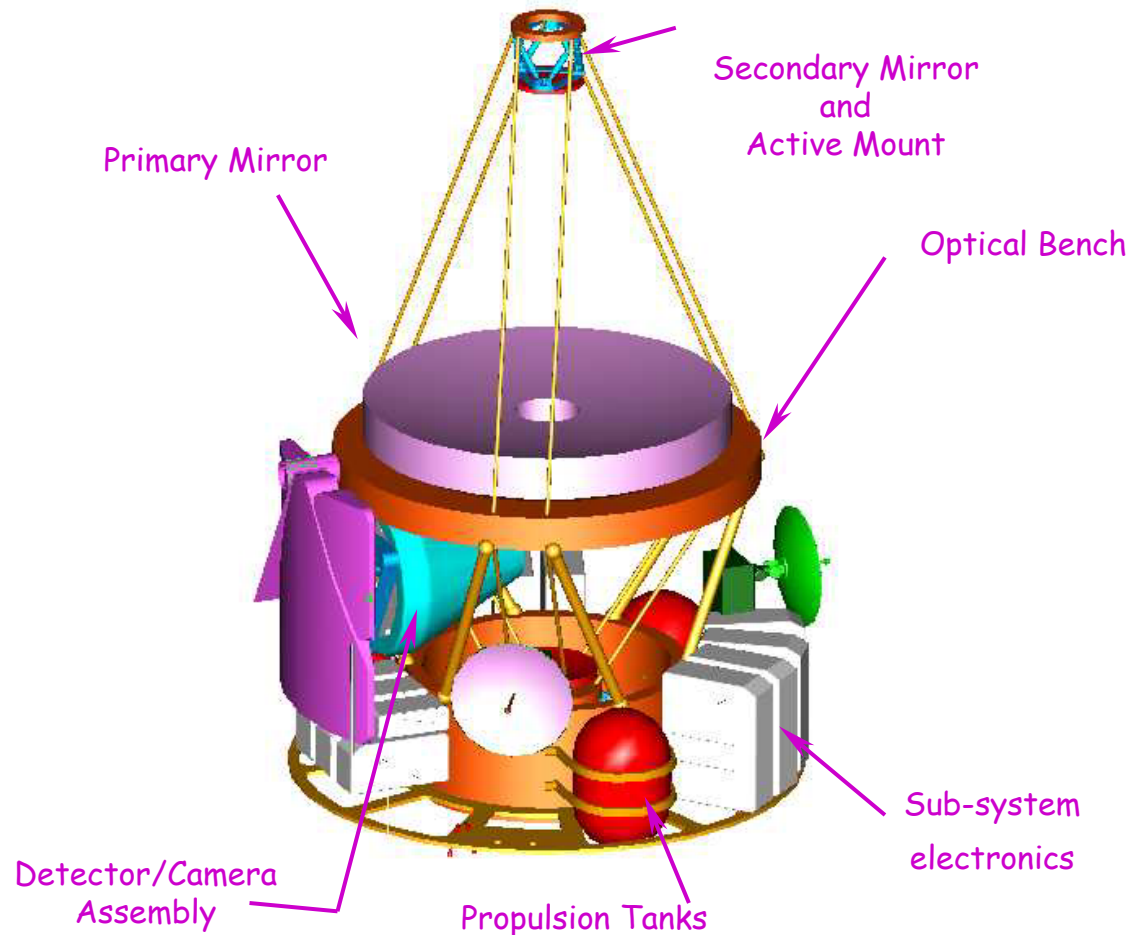
- Discover large numbers of supernovae

- Large 2 meter class telescope, large field of view (0.7 sq degree)
- Dedicated space-based mission



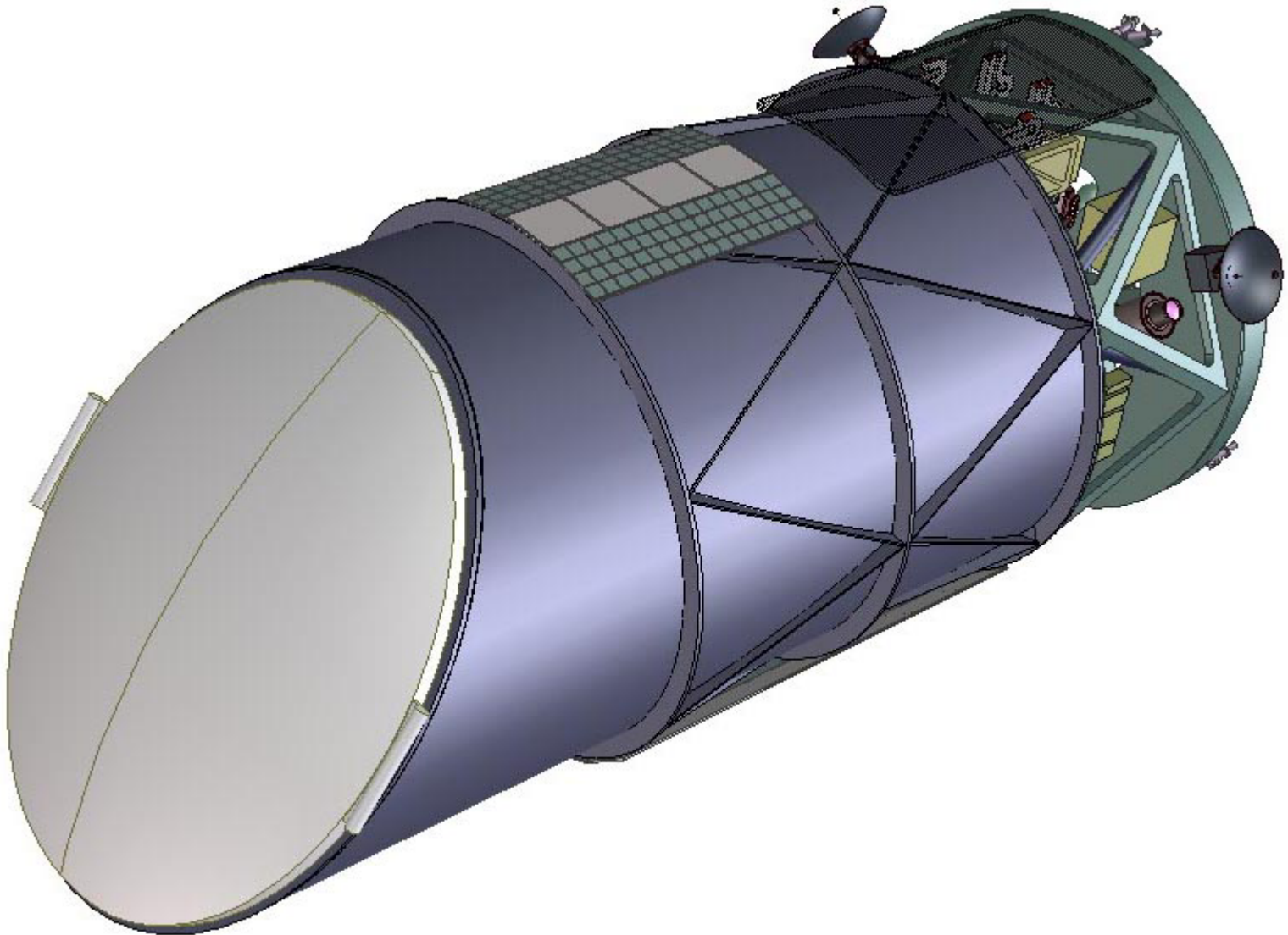
# Telescope

- *2 meter three mirror anastigmat (TMA)*
- *Now in 63rd iteration of design*
- *Focuses light over large focal plane to subpixel point*



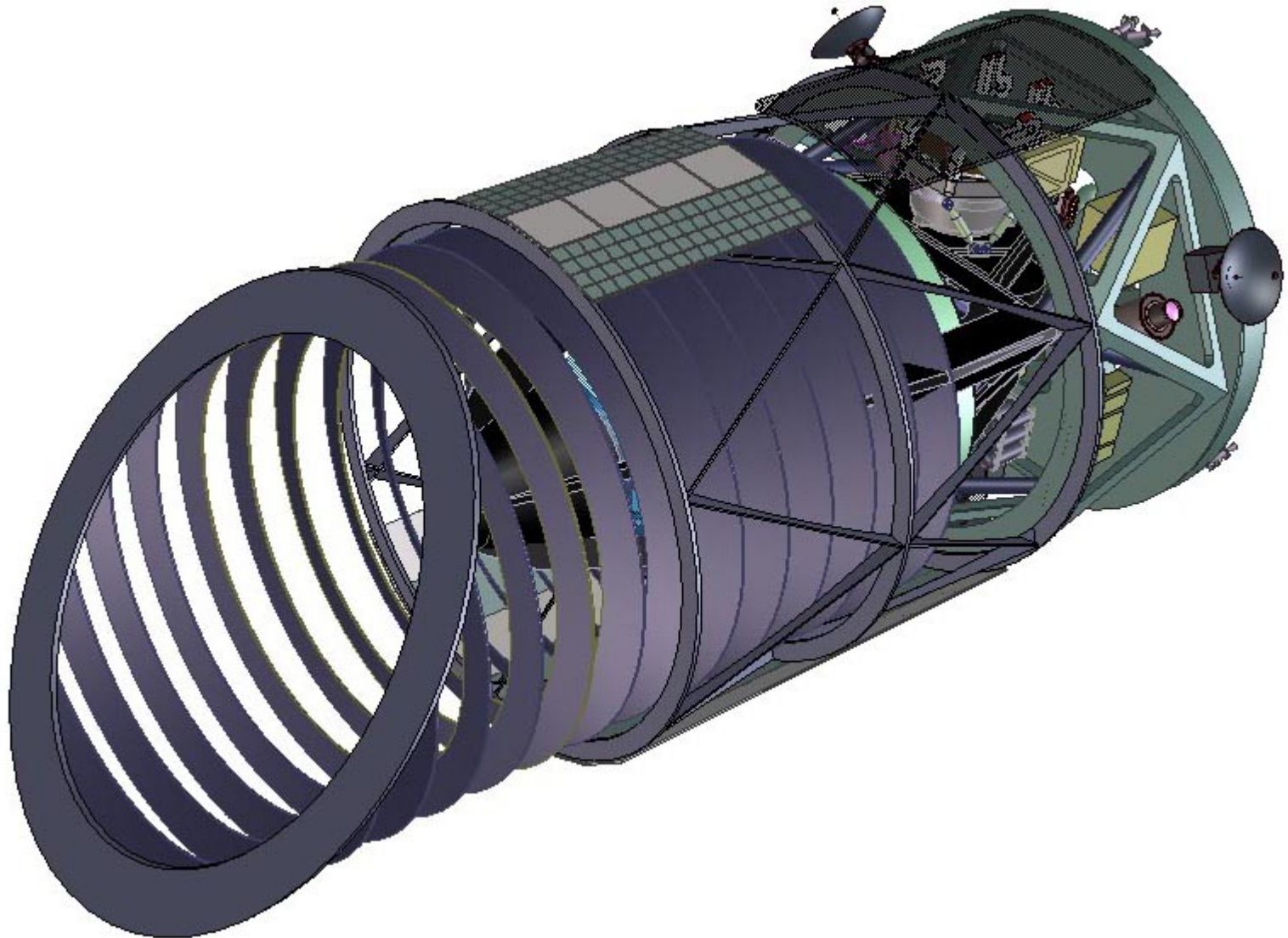


# *Mission Design*



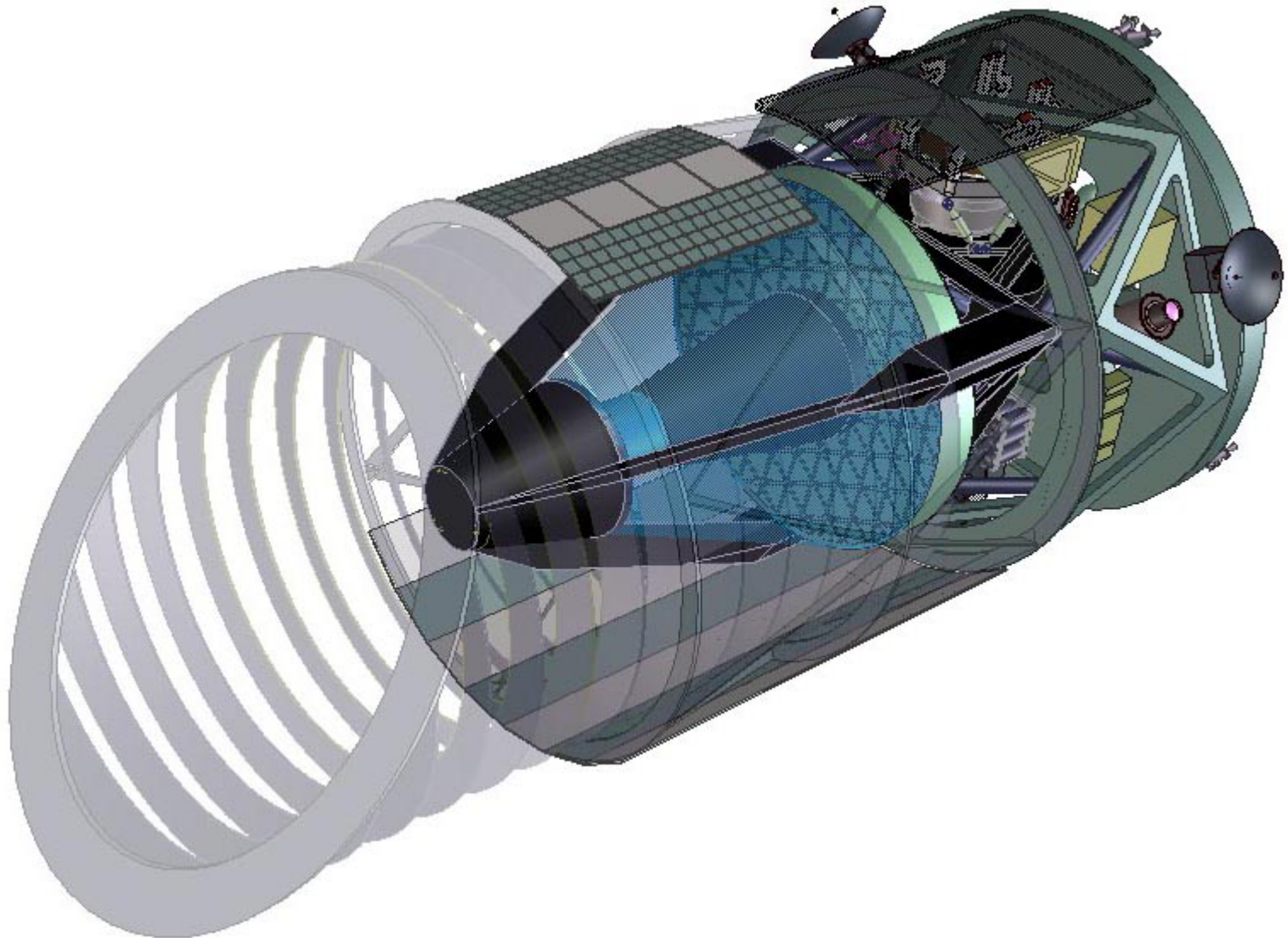


# *Mission Design*



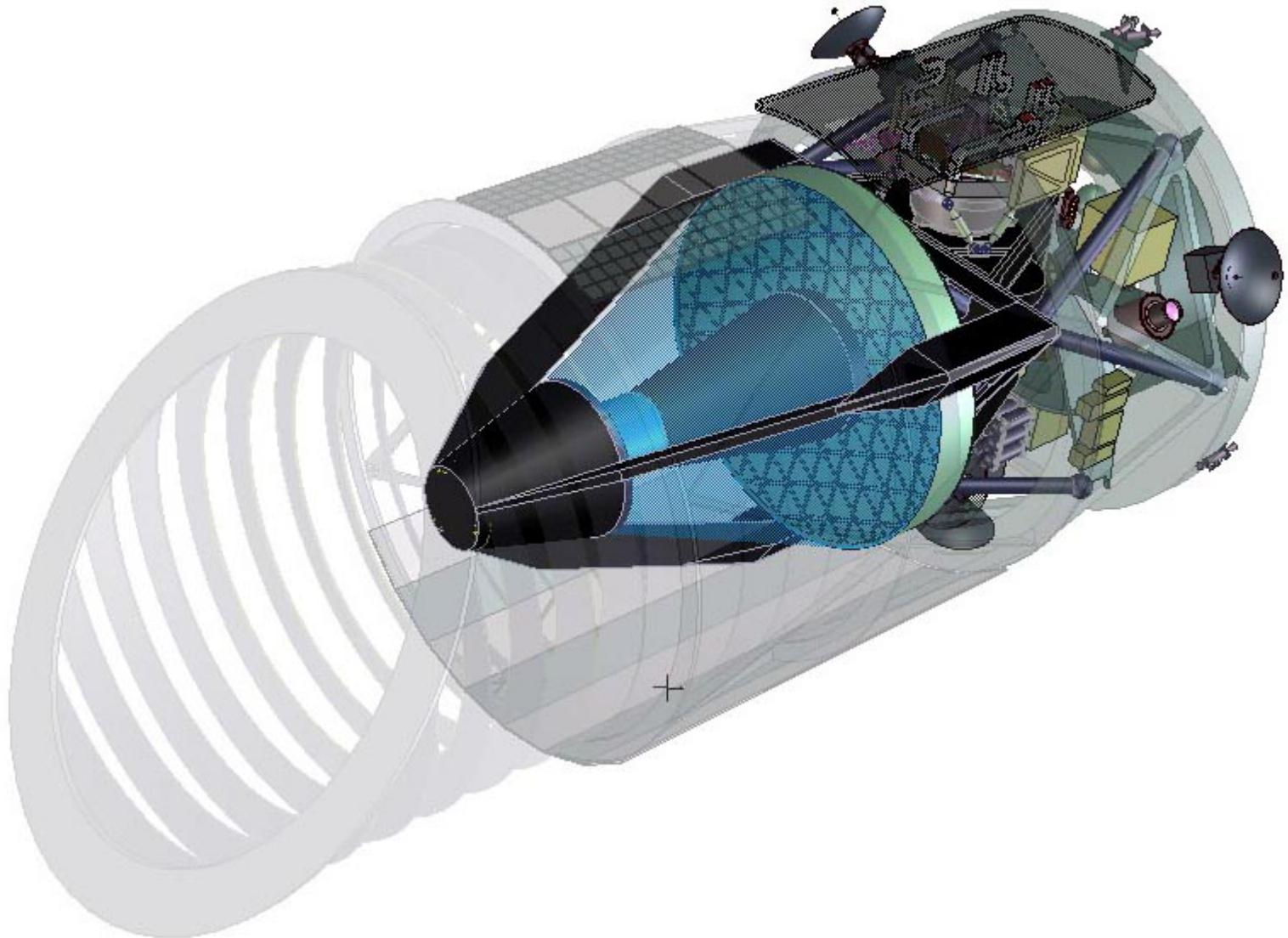


# *Mission Design*



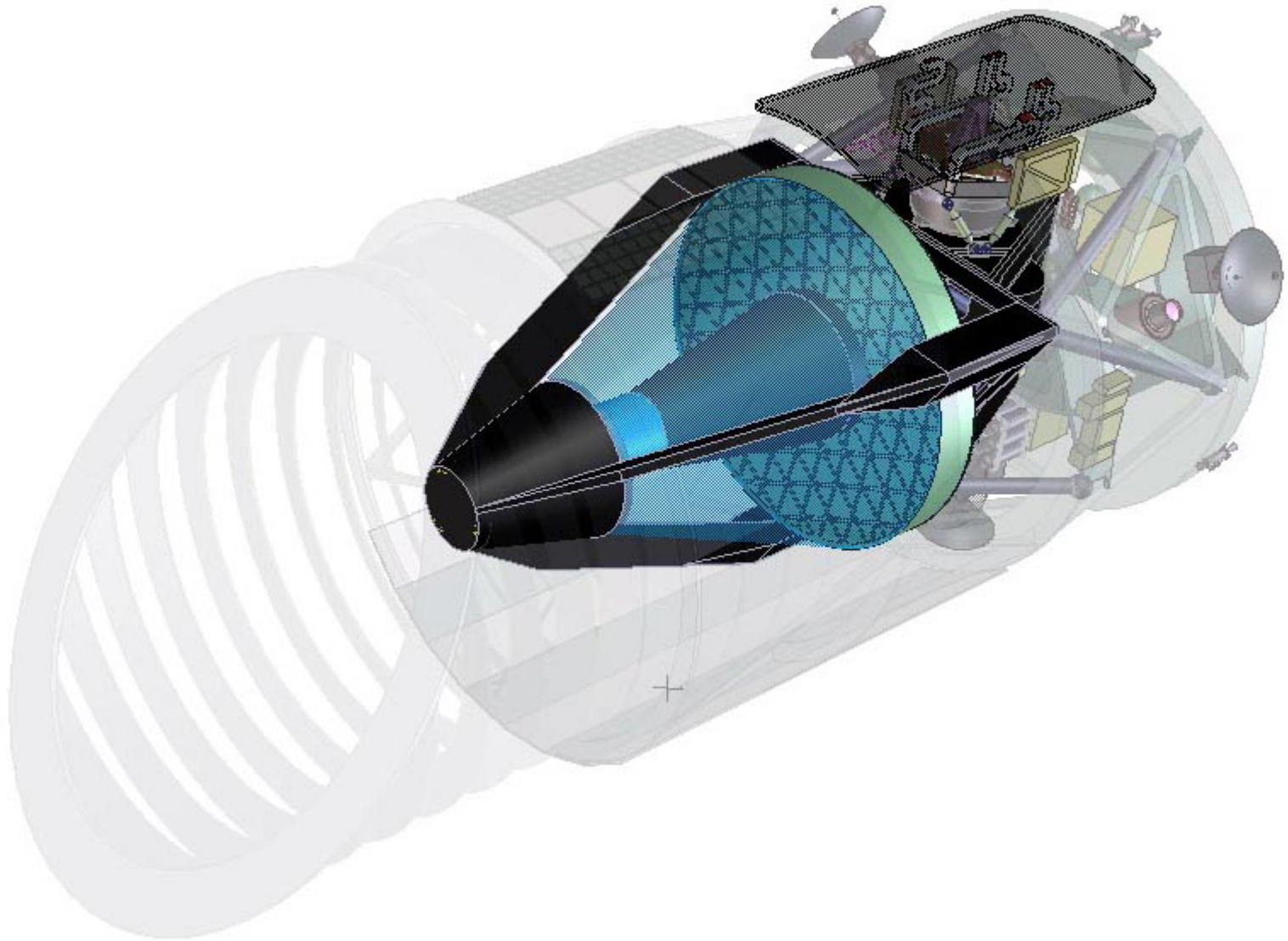


# *Mission Design*



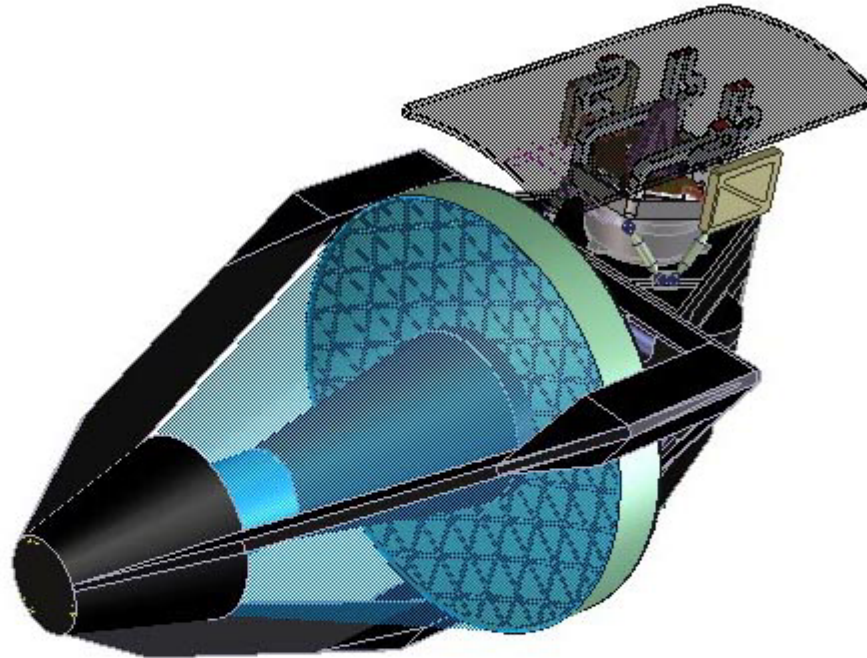


# *Mission Design*



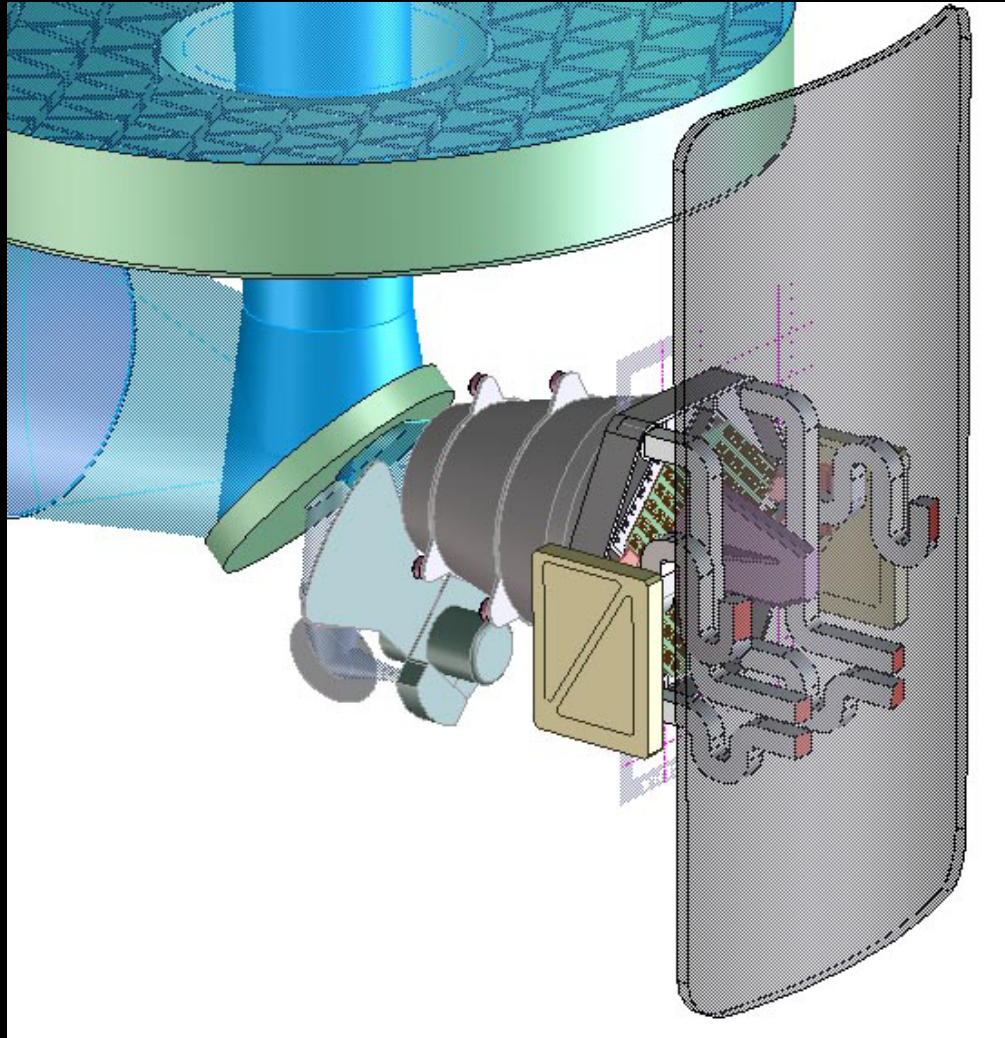


# *Mission Design*



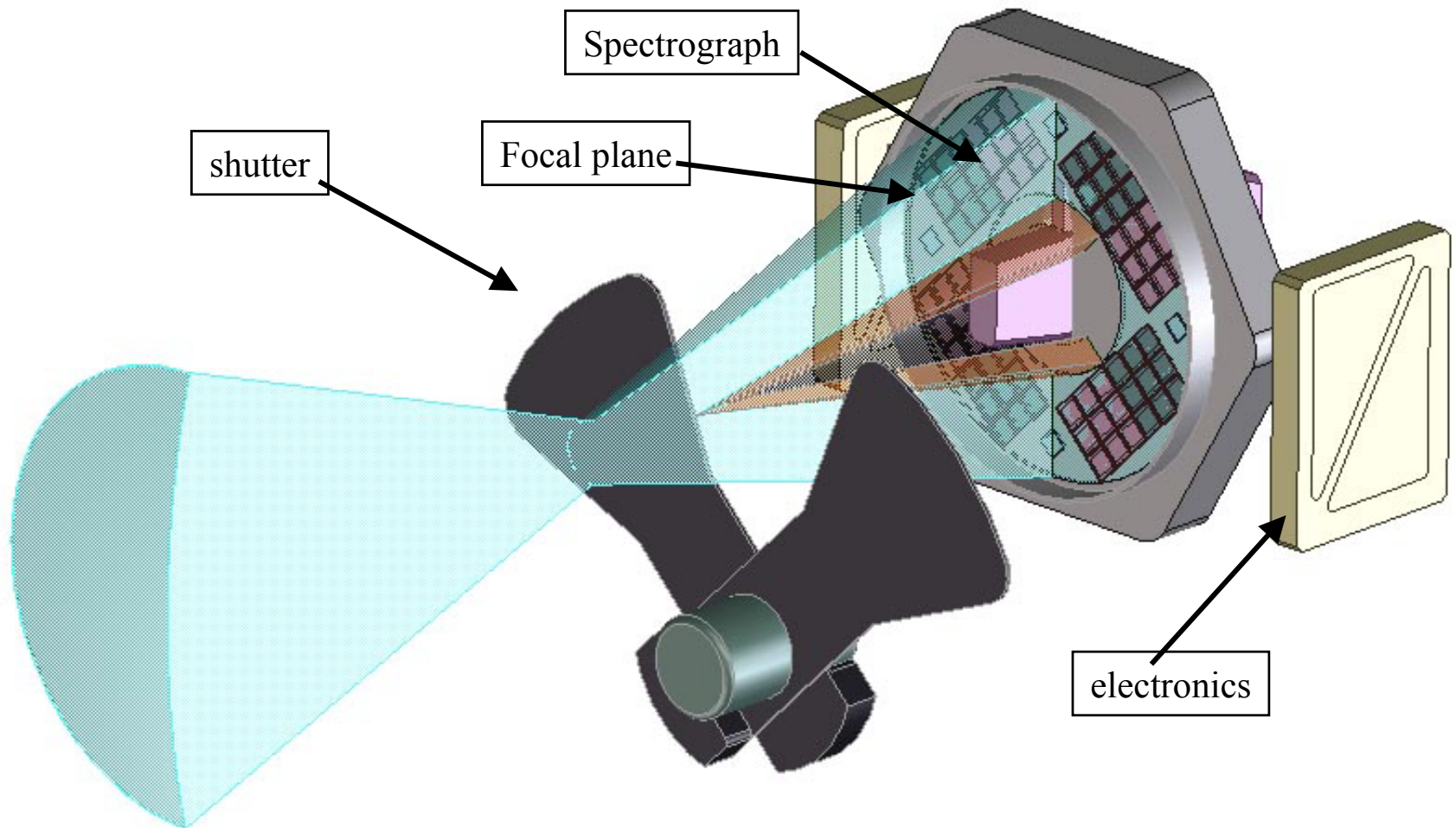


# *Mission Design*





# *Mission Design*





# *From Science Goals to Project Design*



- Discover large numbers of supernovae

- Large 2 meter class telescope, large field of view (0.7 sq degree)
- Dedicated space-based mission

- Look back 3 - 10 billion years ( $z=0.5 - 1.7$ , light is redshifted up to 1.7  $\mu\text{m}$ )

- Visible to near-infrared camera
- Space-based to avoid absorption in earth's atmosphere

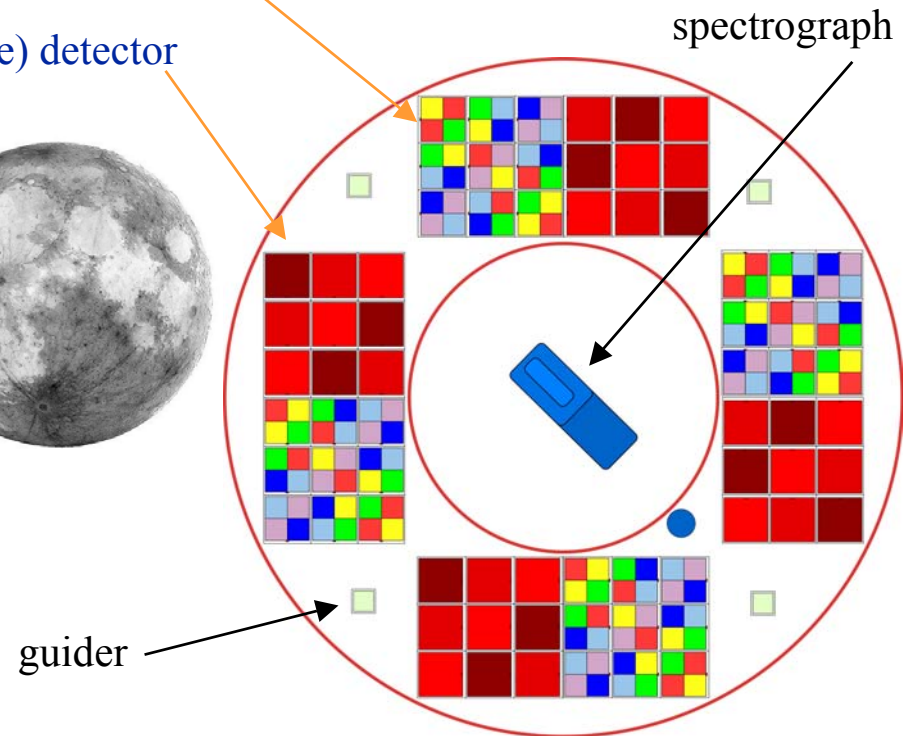
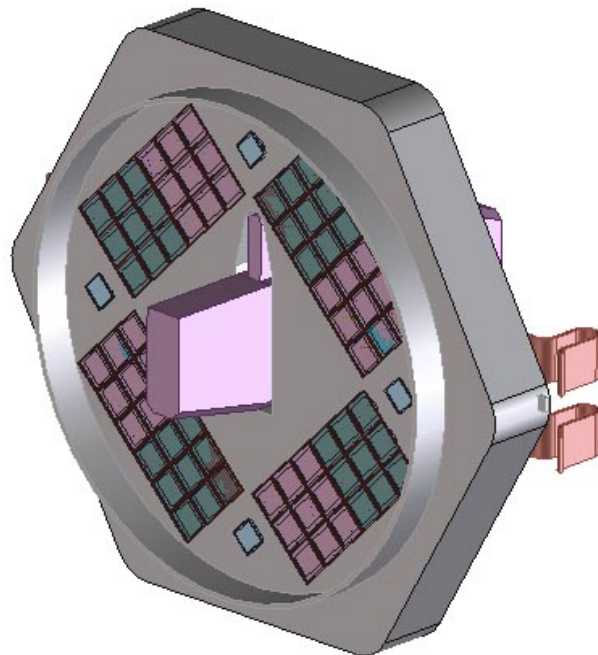


# *Focal Plane Concept*

- Photometry: 0.7° FOV half-billion pixel mosaic camera, high-resistivity, rad-tolerant visible-light and near-IR arrays.

Four filters on each 10.5  $\mu\text{m}$  pixel visible-light (CCD) detector

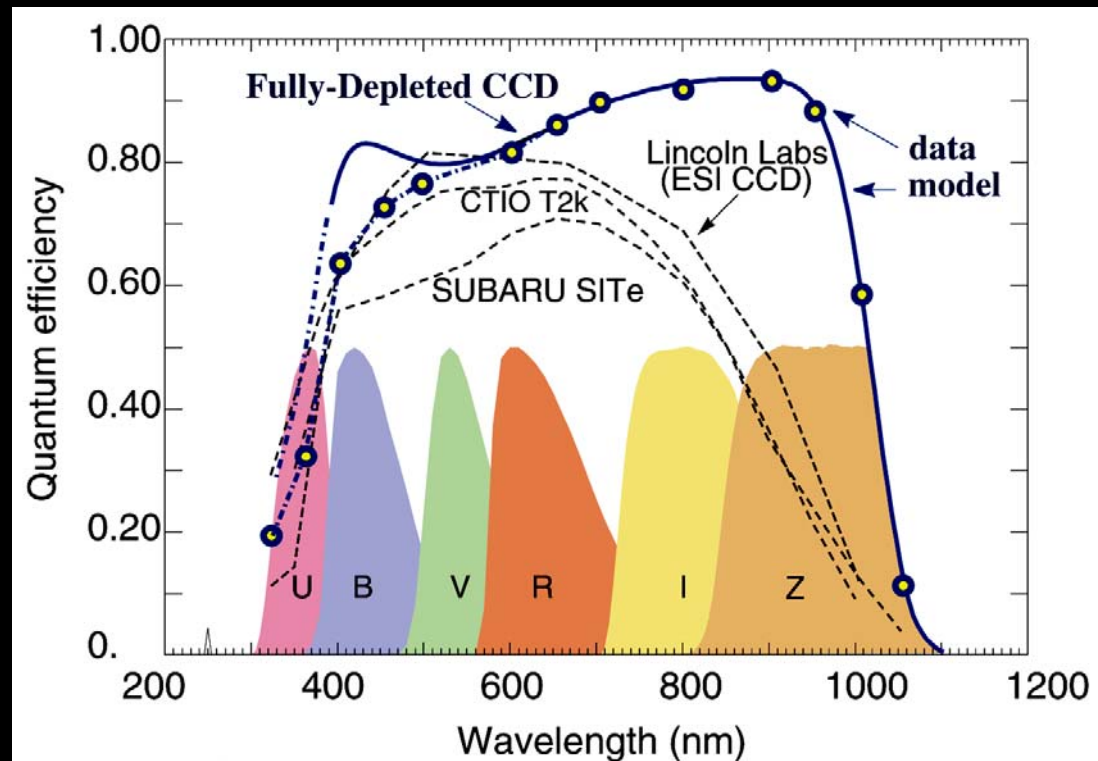
One filter on each 18  $\mu\text{m}$  pixel near-IR (HgCdTe) detector





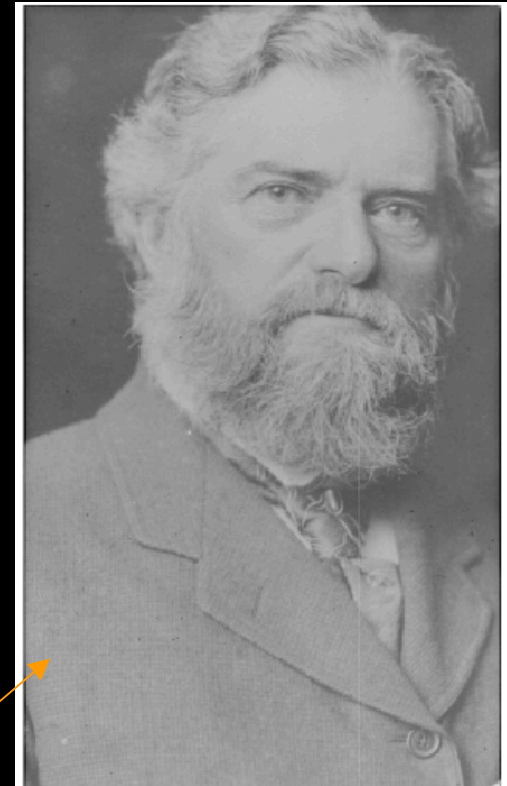
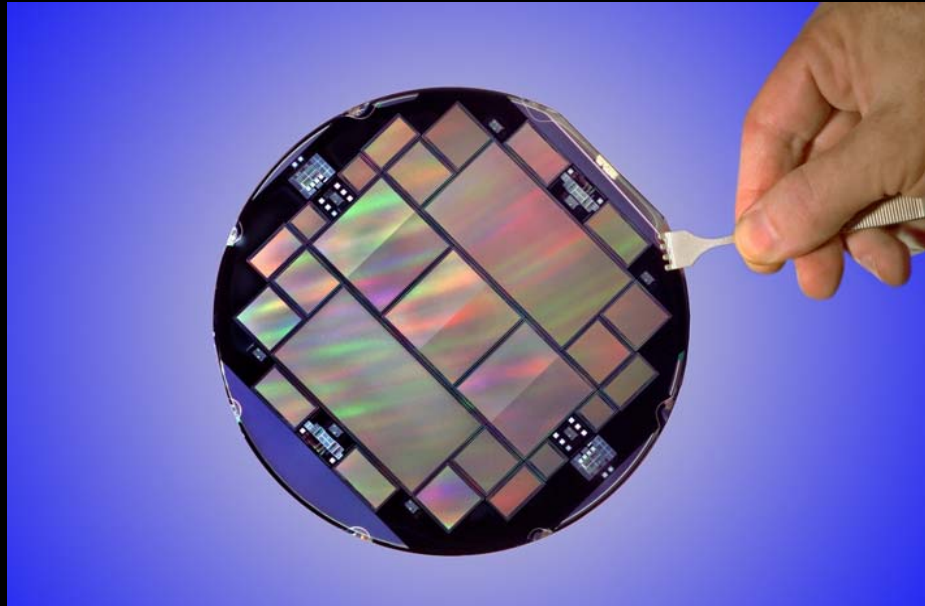
# High-Resistivity CCD's

- New kind of Charged Coupled Device (CCD) developed at LBNL
- Better overall response than more costly “thinned” devices in use
- High-purity “radiation detector” silicon has better radiation tolerance for space applications
- The CCD's can be abutted on all four sides enabling very large mosaic arrays





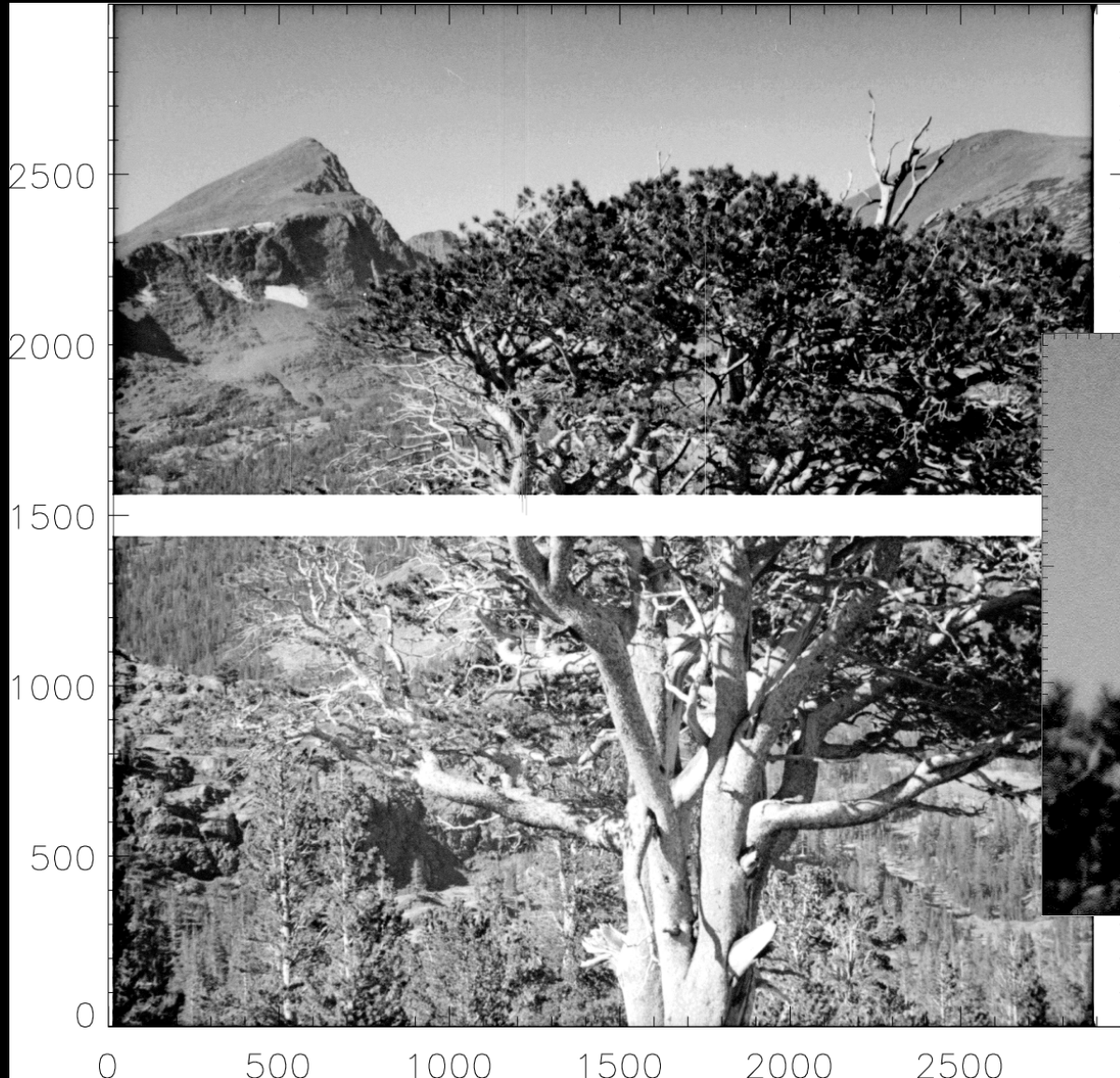
# *LBNL CCD Commercially fabricated on a 150 mm wafer by DALSA Semiconductor*



Front-illuminated 2k x 4k (15 $\mu$ m pixel)  
Back-illumination technology development in progress



# *SNAP Prototype CCD Test Image*



2880 x 2880  
10.5  $\mu\text{m}$  pixels  
Front illuminated



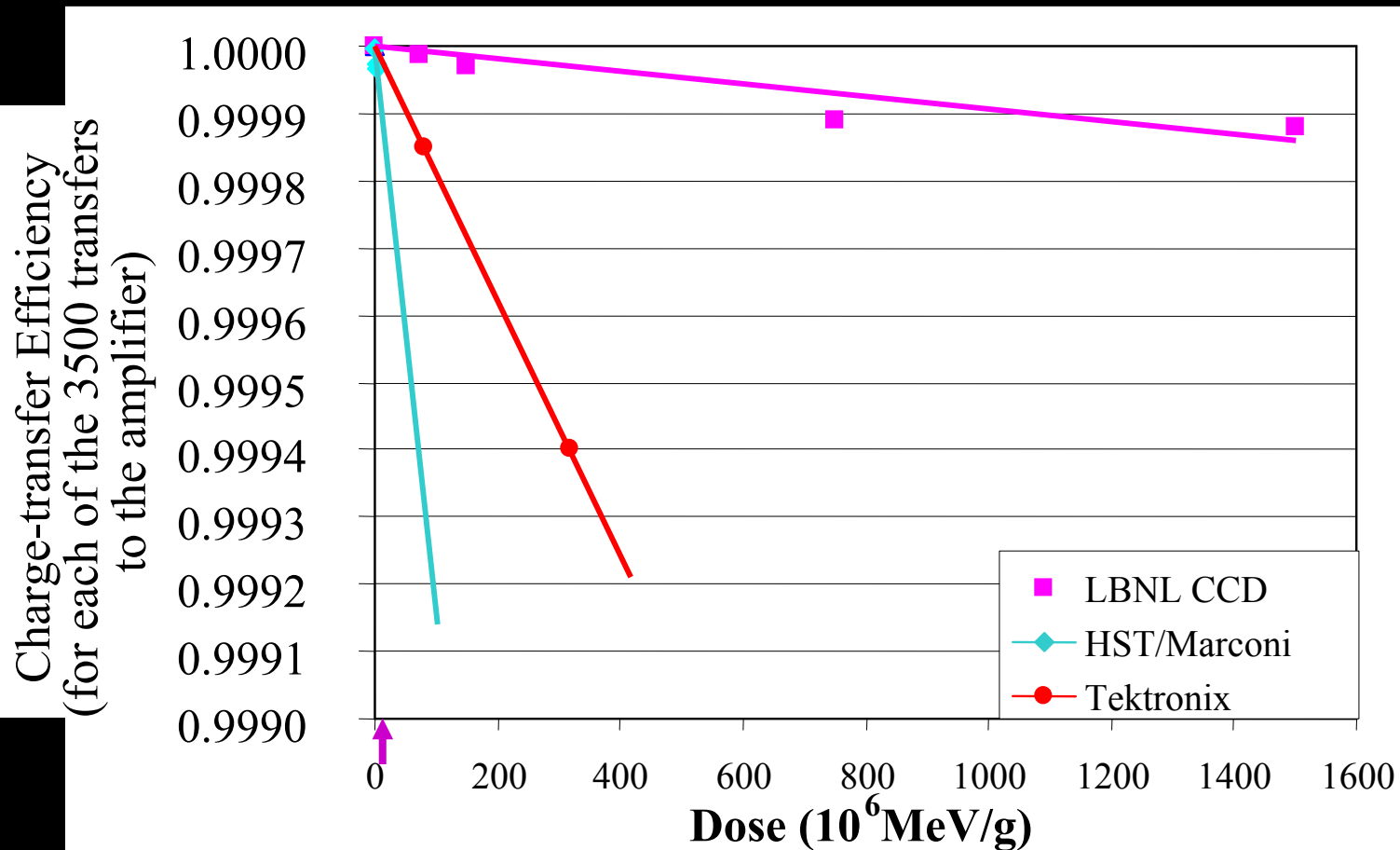


# Improved Radiation Tolerance

Gain is measured using the  $^{55}\text{Fe}$  X-ray method at 128 K.

13 MeV proton irradiation at LBNL 88" Cyclotron

SNAP will be exposed to about  $1.8 \times 10^7$  MeV/g (solar max).





# Readout chip for CCDs now in fabrication

## Goals:

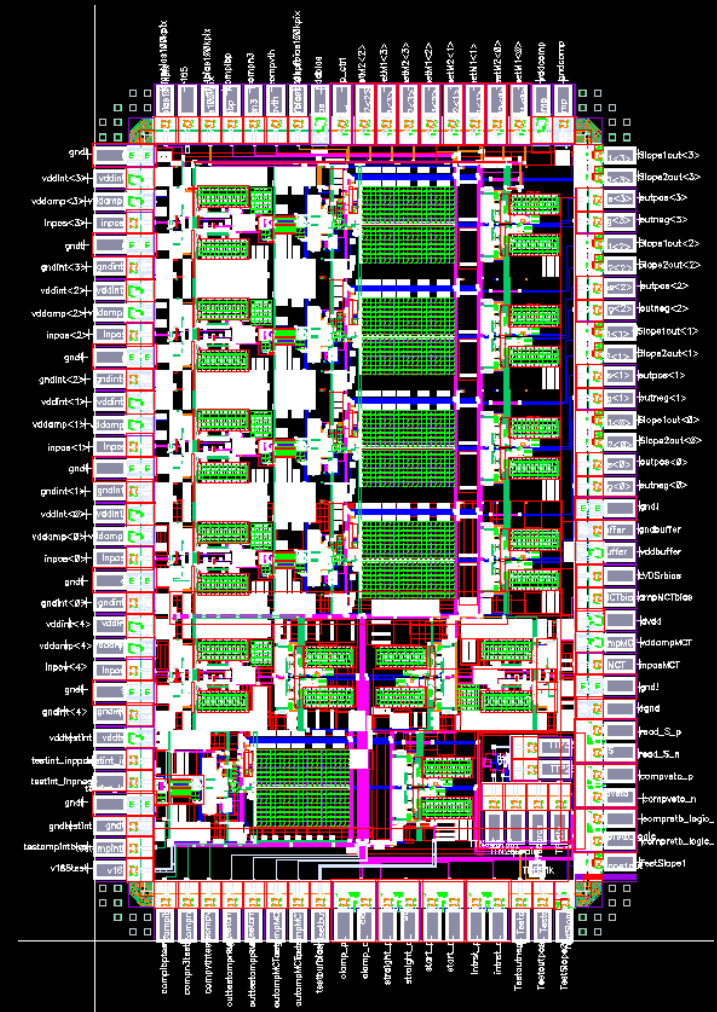
- Photons-to-bits focal plane.
- Eliminate large cable plant.
- Reduce power dramatically.

## ASIC Challenges:

- Large dynamic range.
- Low noise
- Radiation tolerance
- Operation at 140K

## • Status:

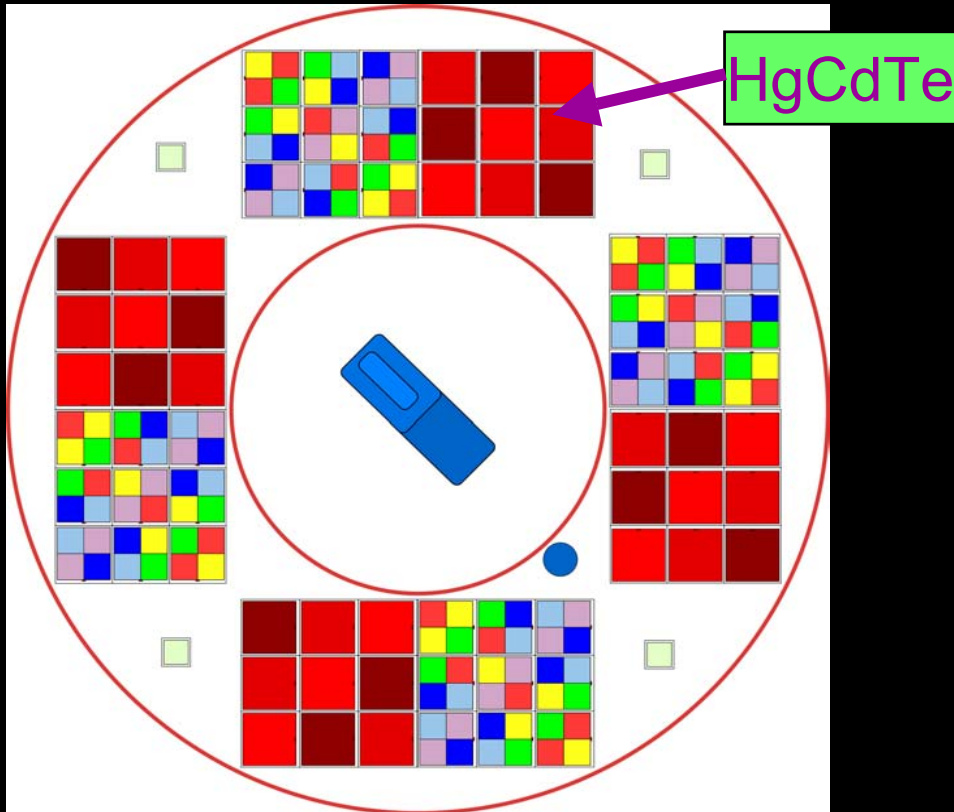
- Prototype ASIC submitted in Jan.





# Near Infrared Sensors

- 150 NIR Megapixels:
- 36 (2k × 2k) 18 μm HgCdTe detectors (0.34 sq. deg)
- 3 special bandpass filters covering 1.0 – 1.7 μm in NIR
- T = 140°K (to limit dark current)

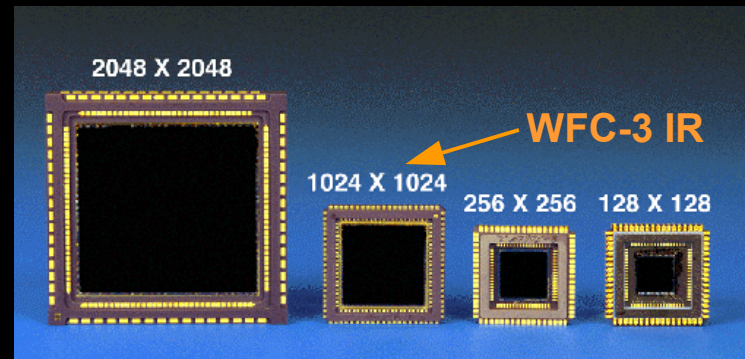


State-of-the-art 2k x 2k HgCdTe detector with 1.7 μm cutoff under development by Rockwell



# *IR Detector Development*

- *Hubble Space Telescope*  
Wide Field Camera 3
  - WFC-3 replaces WFPC-2
  - $1.7\text{ }\mu\text{m}$  cut off
  - $18\text{ }\mu\text{m}$  pixel
- Collaboration growth in area of IR detector development.
  - Experts from Caltech, UCLA, JPL joining the current Michigan effort
- Major R&D contracts to be let imminently to IR detector vendors.





# *From Science Goals to Project Design*



- Discover large numbers of supernovae

- Large 2 meter class telescope, large field of view (0.7 sq degree)
- Dedicated space-based mission

- Look back 3 - 10 billion years ( $z=0.5 - 1.7$ , light is redshifted up to 1.7  $\mu\text{m}$ )

- Visible to near-infrared camera
- Space-based to avoid absorption in earth's atmosphere

- Measure each supernova in detail (light curve, spectrum)

- Detailed spectrum at maximum light to characterize supernovae
- Observing program of repeated images in visible to near-infrared



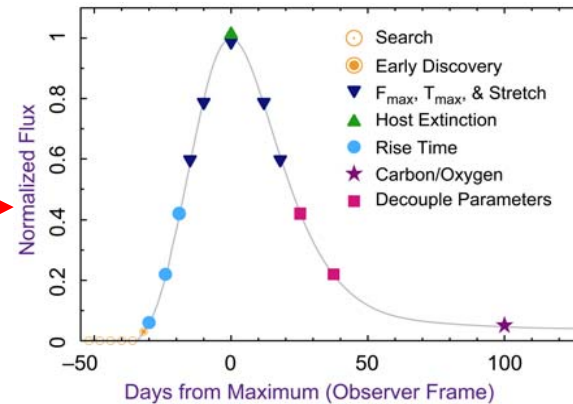
# What makes the SN measurement special?

## Control of systematic uncertainties

At every moment in the explosion event, each individual supernova is “sending” us a rich stream of information about its internal physical state.

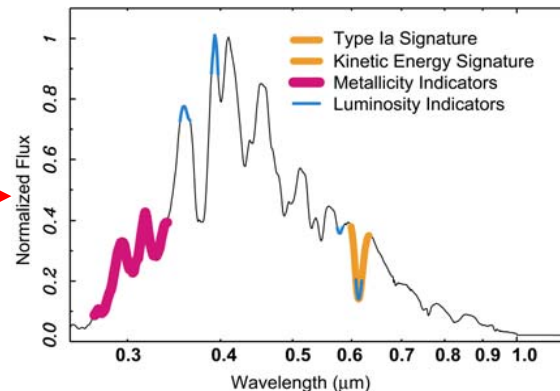
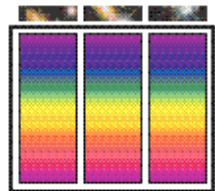
### Lightcurve & Peak Brightness

Images



### Redshift & SN Properties

Spectra

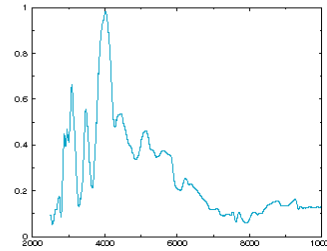
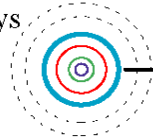




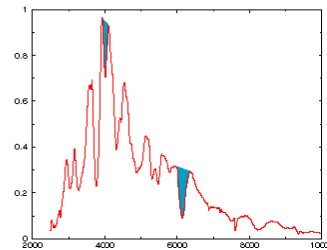
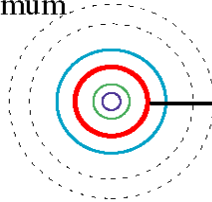
# The Time Series of Spectra is a “CAT Scan” of the Supernova



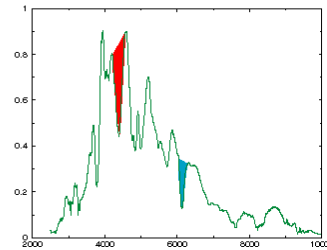
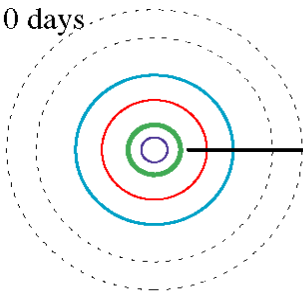
-14 days



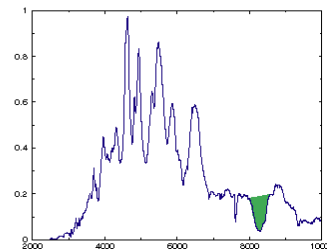
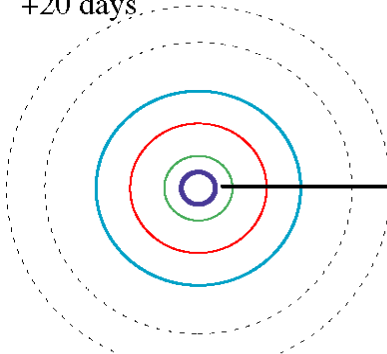
maximum



+10 days



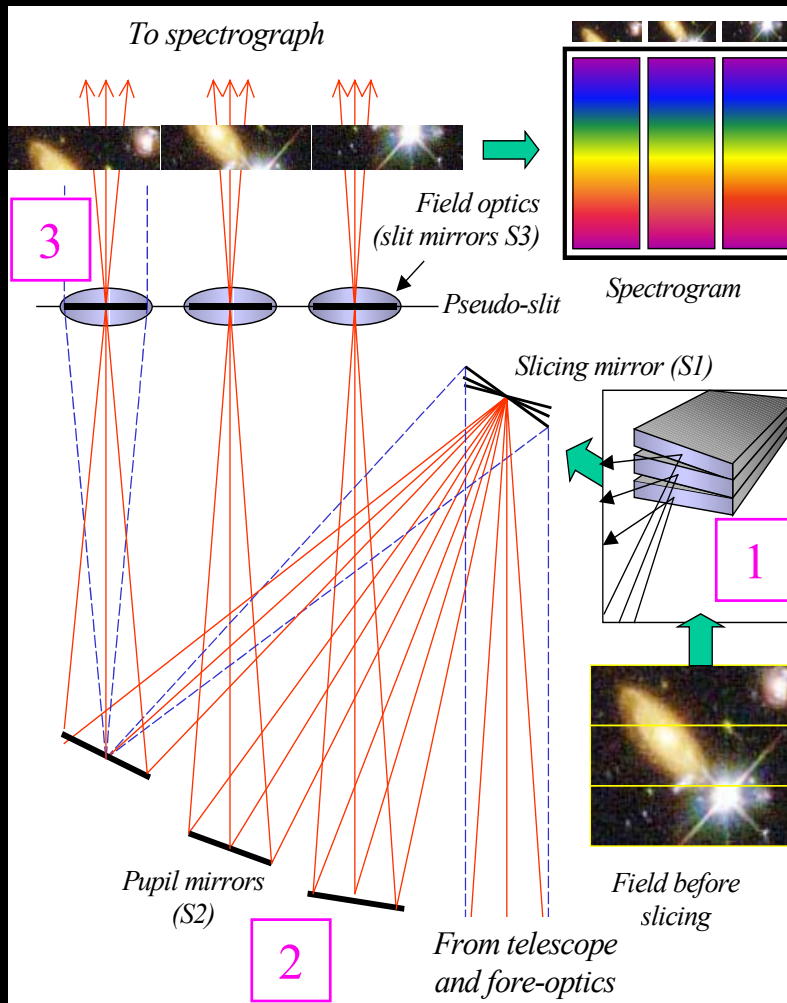
+20 days





# Spectrograph: IFU Slicer principles

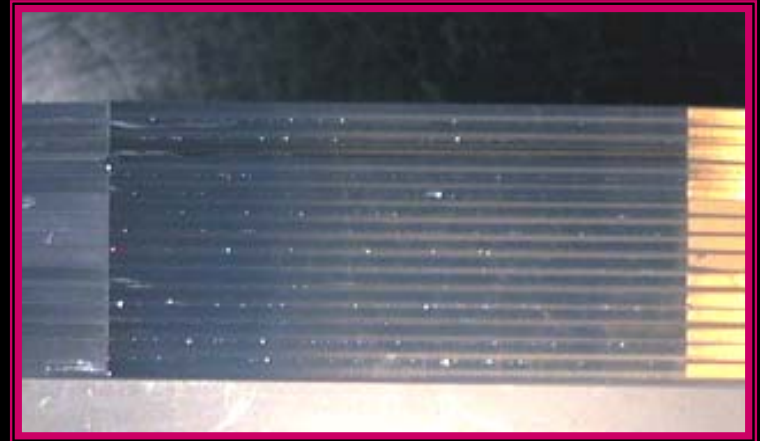
How to rearrange 2D field to enter spectrograph slit:



1. Field divided by slicing mirrors in subfields (20 for SNAP)
2. Aligned pupil mirrors
3. Sub-Field imaged along an entrance slit



# *Mirror Slicer Stack* (L.A.M. – Marseille)

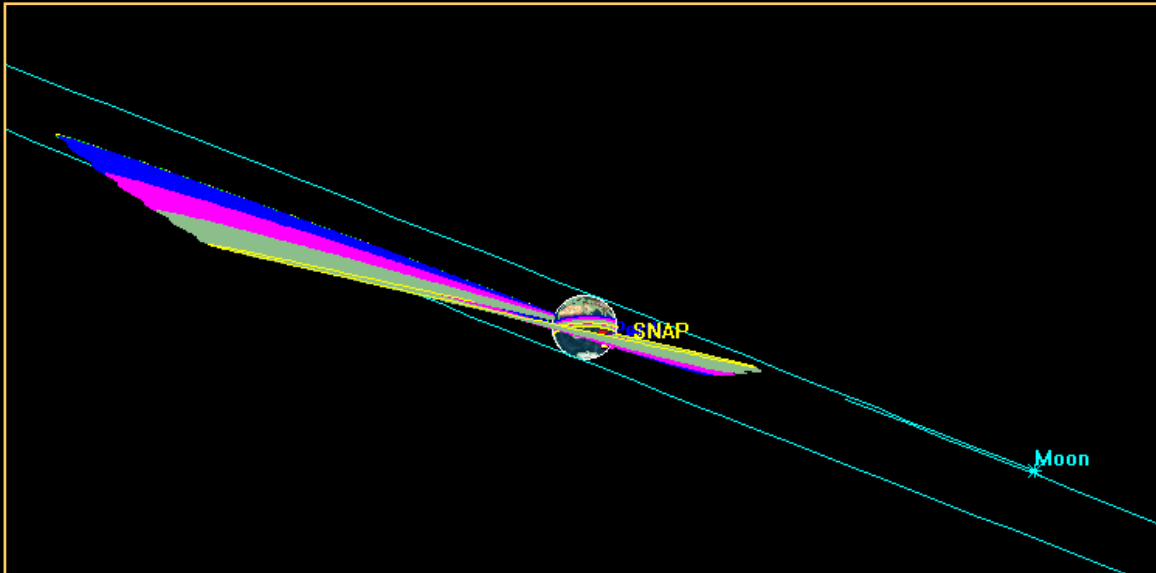
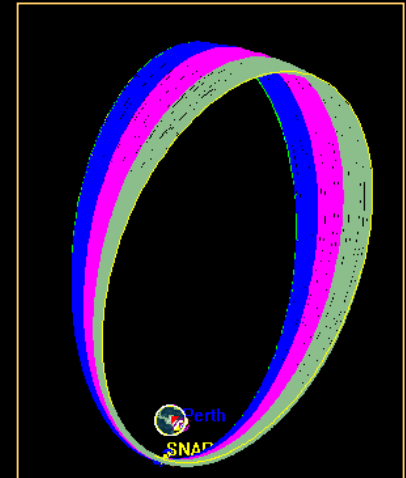




# Orbit



- **High Earth, 3 day synchronous orbit**
- **Good Overall Optimization of Mission Trade-offs**
- **Orbit Provides Multiple Advantages:**
  - Minimum Thermal Change on Structure
  - Excellent Coverage from Berkeley Groundstation
  - Passive Cooling of Detectors
  - Minimizes Stray Light





# *SNAP Status*



- HEPAP subpanel (Bagger-Barish) recommended that SNAP R&D proceed
- Full Lehman review of SNAP R&D plan in July 2002 - passed with flying colors
- Anticipate first full year of R&D funding will be in FY04
  - establish key technologies, define requirements, build collaboration.
  - Two year R&D phase, culminating in a conceptual design.



# *NASA interest in working with DOE on SNAP*



“The U.S. Department of Energy (DOE) has made the mystery of dark energy a high science priority and, under the leadership of its Lawrence Berkeley National Laboratory, is funding a study of a possible space mission entitled the Supernova Acceleration Probe (SNAP) to address this topic. Therefore, in order to encourage consideration of all possible approaches, as well as the potential of interagency collaborations, mission concept proposals for the Dark Energy Probe in response to this NASA solicitation may be of two types, both of which are encouraged with equal priority:

“Type 1: Proposals for a full mission investigation concept that uses any technique to meet the science goals of the Dark Energy Probe; and

“Type 2: Proposals involving a significant NASA contribution (> 25% of the total mission cost) to the existing DOE SNAP concept mission.”



# *Conclusion*



- Dark energy is an important fundamental constituent of our Universe, but we know very little about it.
- SNAP will test theories of dark energy and show how the expansion rate has varied over the history of the Universe.
- The technology is at hand and R&D is proceeding rapidly.



# The Expansion History of the Universe

